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**DOCTOR OF PHILOSOPHY**

# Essays on the Economics of Renewable Energy

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# Essays on the Economics Of Renewable Energy

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Thesis submitted for the degree of
Doctor of Philosophy

The University of Glasgow
Faculty of Law, Business, and Social Sciences
Economics Department

May 2006

# Abstract

Scotland is entering a transition period for its environment and economy as it decides which path to follow in meeting its energy and electric power needs over the coming decades. This thesis describes and evaluates several of the major dimensions which will contribute to those decisions and see welfare improvements for individuals and society in Scotland.

Chapter One presents the current state of energy consumption in Scotland and provides technical details to understand the role of power generation. The dramatic need to plan replacement of an aging power infrastructure is also documented. The United Kingdom's international commitment to the European Union and the United Nations for reducing green house gas emissions and how that commitment is shared around the world is reviewed. Finally, Scotland is compared to several European countries on the basis of government policies and attainment of renewable energy deployment.

Chapter Two describes the current policy initiative in Scotland to use market mechanism to incentivise the deployment of renewable power technologies. The operation and effectiveness of the Renewables Obligation (Scotland) program is described and analysed in depth.

Chapter Three is a literature review of public perceptions, opinions and attitudes toward renewable energy. This chapter also presents evidence about the value of environmental changes that may occur with the deployment of renewable technologies. The environmental concerns examined are landscape, wildlife, and air pollution.

Chapter Four presents a choice experiment to estimate the value of environmental changes and employment which may occur from renewable energy projects being built around Scotland. The household willingness-to-pay was estimated. Significant differences between urban and rural values were identified in regards to environmental impacts. Rural populations were found to value environmental impacts lower in exchange for the employment and economic development that would result locally from energy projects being built.

Chapter Five discusses some of the controversial issues and technical problems with choice experiments.

Chapter Six is a game theory model of interactions between small renewable energy producers and a large dominant traditional power producer. This chapter develops a model which better represents the actual behaviour and functional operating environment of the green certificate market. The model consists of two power producers producing an identical product (electricity); the dominant producer uses only brown fuels and is required to purchase green certificates from the fringe green firm. The model attempts to find the policy and market equilibrium points for two firms trading two goods in two markets while minimising the cost to society of a green certificate program.

The final chapter presents the major findings of this thesis and concludes by advocating policies which would address the goal of maximising social welfare from the deployment of renewable energy technology in Scotland.

## Declaration

I hereby declare that this thesis represents my own work unless otherwise stated in the body of the thesis.

May 2006

Eric Ariel Bergmann

*"Sunshine is a form of energy, wind and sea currents are manifestations of this energy. Do we make use of them? Oh No! We burn forests and coal, like tenants burning down our front door for heating. We live like wild settlers and not as though these resources belong to us"*

*Thomas Edison, 1916*

### *Dedication*

*To my parents, Mary Bergmann and Glenn Bergmann, who never wavered in support and belief that I could pursue and fulfil my dreams.*

*To Mrs. Tesitore, Mr. Wally Larson, Mr. Larry Johnson, and Mr. Larry Senesh; Teachers who encouraged, inspired and taught me to never quit learning and seeking out new ideas.*


### Acknowledgements

I would like to thank Nick Hanley for his guidance, knowledge, and support, but most of all for his patience and friendship during the years of research and writing of this thesis. He provided the cornerstone on which I have built this work.


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## Acronyms

| | |
|---|---|
| ASCs | Alternative specific constants |
| BWEA | British Wind Energy Association |
| EC | European Commission |
| EMEC | European Marine Energy Centre |
| EU | European Union |
| CCGT or CC | Combined cycle gas turbine |
| CCL | Climate Change Levy |
| CE | Choice Experiment |
| CM | Choice Modeling |
| CSA | Countryside Agency |
| FFL | Fossil Fuel Levy |
| GHG | Green house gases |
| IIA | Independence from Irrelevant Alternatives |
| OFGEM | Office of Gas and Electricity Markets |
| MEC | Marginal external cost |
| MNL | Multinomial Logit |
| MSC | Marginal social cost |
| MSB | Marginal social benefit |
| MPC | Marginal private cost |
| MW | Megawatt |
| NIRO | Northern Ireland Renewables Obligation |
| NL | Nested logit |
| NFPAS | The Non-Fossil Purchasing Agency (Scotland) |
| OLS | Ordinary least square |
| TGCs | Tradable green certificates |
| REFIT | Renewable energy feed-in tariff |
| RES or RES-E | Renewable Energy Sources –Electric |
| ROC | Renewable Obligation Certificates |
| RO | Renewables Obligation |
| ROS | Renewables Obligation (Scotland) |
| RPL | Random Parameters Logit |
| RUT | Random Utility Theory |
| SEPA | Scottish Environmental Protection Agency |

**(continued next page)**

## Acronyms

(continued)

| | |
|---|---|
| SP | Scottish Power |
| SRO | Scottish Renewables Order |
| SSE | Scottish and Southern Energy |
| SWT | Scottish Wildlife Trust |
| TGC | Tradable Green Certificate |
| UK | United Kingdom |
| UN | United Nations |
| UNFCCC | United Nations Framework Convention on Climate Change |

### Electric Power Terms

| | |
|---|---|
| kWh | kilowatt-hour |
| GWh | Gigawatt-hour |
| MWh | Megawatt-hour |
| TWh | Terawatt-hour |

### Green House Gases

| | |
|---|---|
| CO2 | Carbon dioxide |
| CH4 | Methane or Natural gas |
| CFC | Chlorofluorocarbon |
| HFC | Hydrofluorocarbons |
| N2O | Nitrous oxide |
| SF6 | Sulfur hexafluoride |

# Chapter 1

## *Introduction and Background*

**Chapter Sections**

Introduction

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SPAIN

RES targets

Status of the renewable energy market

Main supporting policies

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## *Introduction*

In 2003, the Government of the United Kingdom published a White Paper outlining the direction energy policy should pursue for the next 10 years. The document, *Our Energy Future – Creating a Low Carbon Economy* (DTI, 2003), called for a 60% reduction in carbon dioxide emissions by 2050. This announcement marked the greatest commitment any UK government had ever given to pursuing a sustainable energy policy and shifting away from long established fossil fuel energy sources. Environmentally clean, renewable energy sources were identified as a vital contributor to attaining the "Low Carbon" vision. To emphasize the importance of renewables the allocation of an additional £60 million in capital grants was announced, to demonstrate increased support and to stimulate near-term renewable energy technologies (DTI, 2003).

Scotland followed the White Paper's lead with its own announcement, the "aspiration" to increase electricity generated from renewable energy sources. A goal was set to increase green power from 10% level of all electricity generated in 2003 and move toward a 40% level in 2020, with an intermediate goal of 18% by 2012 (Scottish Executive, 2002b). For a nation without significant potential for developing new hydroelectric sources (BHA, 2004), Scotland's aspiration is one of the most ambitious in the world.

The ubiquitous nature of electricity, and all the technology which depends on its availability, may be the defining notion of a modem developed economy and society. It is considered the greatest engineering achievement of the $20^{th}$ century (NAE, 2004). The system based on large-scale power generation, large-scale transmission grids, and vast local distribution networks has been the dominant model used for delivering electricity to consumers since commercial power companies were started by Thomas Edison 120 years ago (IEEE, 2003).

The proposed expansion and reliance on even greater levels of renewable energy sources will challenge the fundamental structure of the power industry. It will require new paradigms and technologies in the delivery of electric energy and energy is used by society (Strbac, 2002). It may well require a fundamental change in how society perceives the use of electric power, how it is used at home and at work, and its effect on lifestyle values. For example, the geographically dispersed nature of wind will require hundreds of wind turbines located in dozens of wind farms to produce the same amount of energy as a single coal-fired power plant; is society ready to accept that landscape change for clean energy?

The electricity transmission grid may become less important for long distance transmission of electric power and re- oriented to regional sharing, to allow for the intermittent quality of some forms of renewable energy; how will that change the business practices for energy firms? Local communities may have the opportunity to provide their own electric power by owning and operating renewable energy projects; how will that effect rural development and community political empowerment?

Industries which consume large quantities of power may have to adapt traditional operation practices to new standards, like scheduling production to match electric power availability instead of power being available upon demand, i.e., shifting from day to night-time operations.

## Global Climate Change

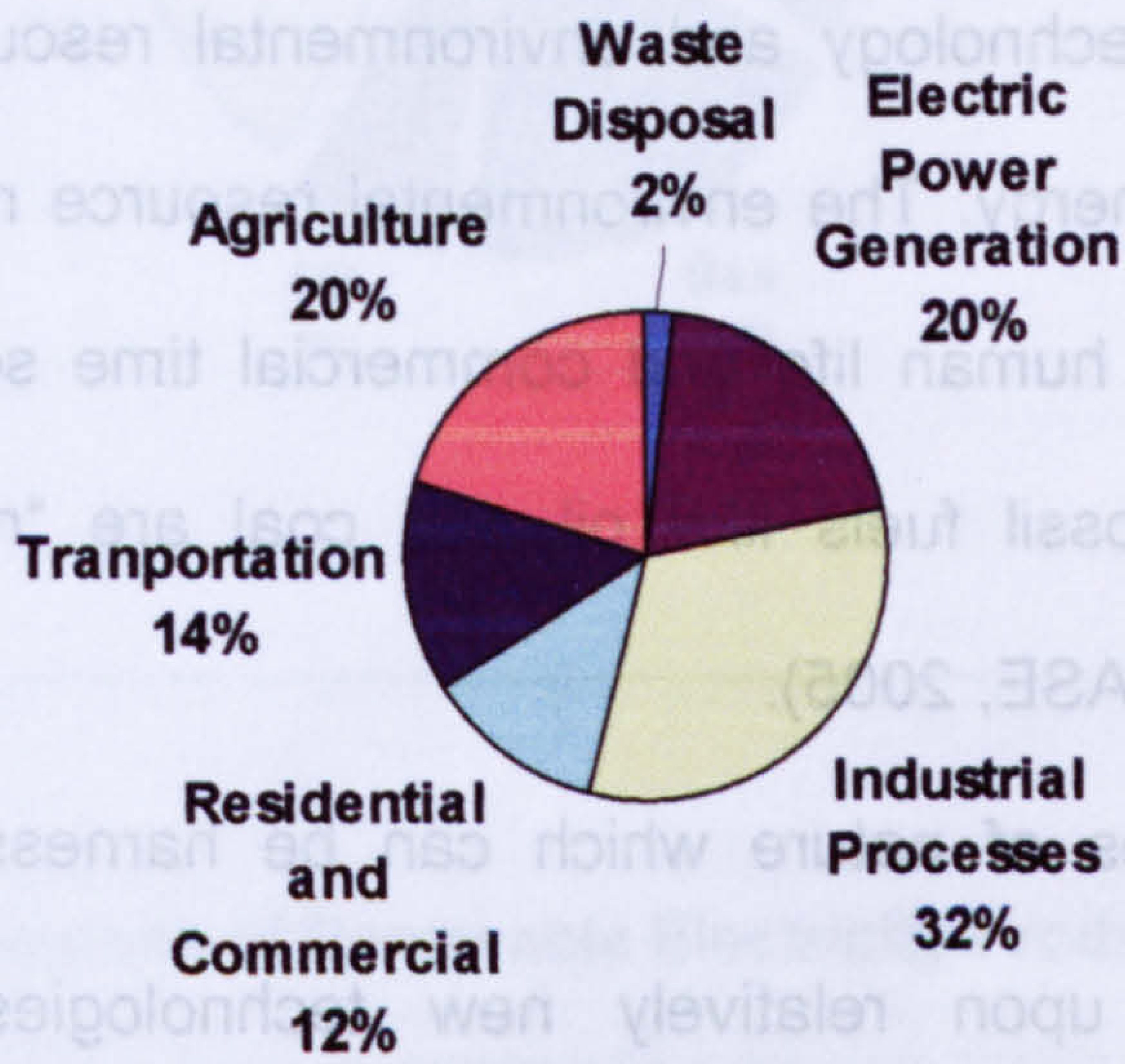
The principle motive for renewable energy development in the United Kingdom is a growing concern about the effect of green house gases (GHG) which are being emitted into the atmosphere (DTI, 2003). This concern is global (UN, 2003) and concentrates on climate changes which will harm human populations and the ecosystems which people depend upon. Electric power production is the single largest source of GHG emissions in Scotland (Scottish Executive, 2002a) and the second largest source in the world (Pew, 2004). The author accepts the premise of anthropogenic climate change and does discuss or debate the issue within this dissertation, but treats anthropogenic climate change an exogenous fact accepted by the majority of nations and people of the world[1] . This motivation leads to the ambition of reducing the use of primary energy sources like coal and natural gas for the production of electricity.

New institutions have been created to act on the issue of global climate change. The desire to reduce GHG emissions exists at numerous levels of society, from local villages to the international community. The Climate Change Convention and the Kyoto Protocol are international

[1] As of 27 February 2006, 162 states and regional economic integration organizations have deposited instruments of ratifications, accessions, approvals or acceptances. The total percentage of Annex I Parties emissions is 61.6% (UNa, 2006)

agreements dealing with this issue (UN, 2003). The European Union (EU) has passed Directive 2001/77/EC, also known as the *Renewable Electric Sources* (RES) Directive (EC, 2001), which sets out renewable energy objectives for each

**Chart 1.1 Global Sources of Anthropogenic GHG Emissions**




(Pew, 2003)

Member state, as a portion its total electric energy consumption. And Scotland which has set aside £9 million to assist communities in building renewable energy systems which can be maintained and operated by the local community (SCHRI, 2004).

## Terminology and Technical Information

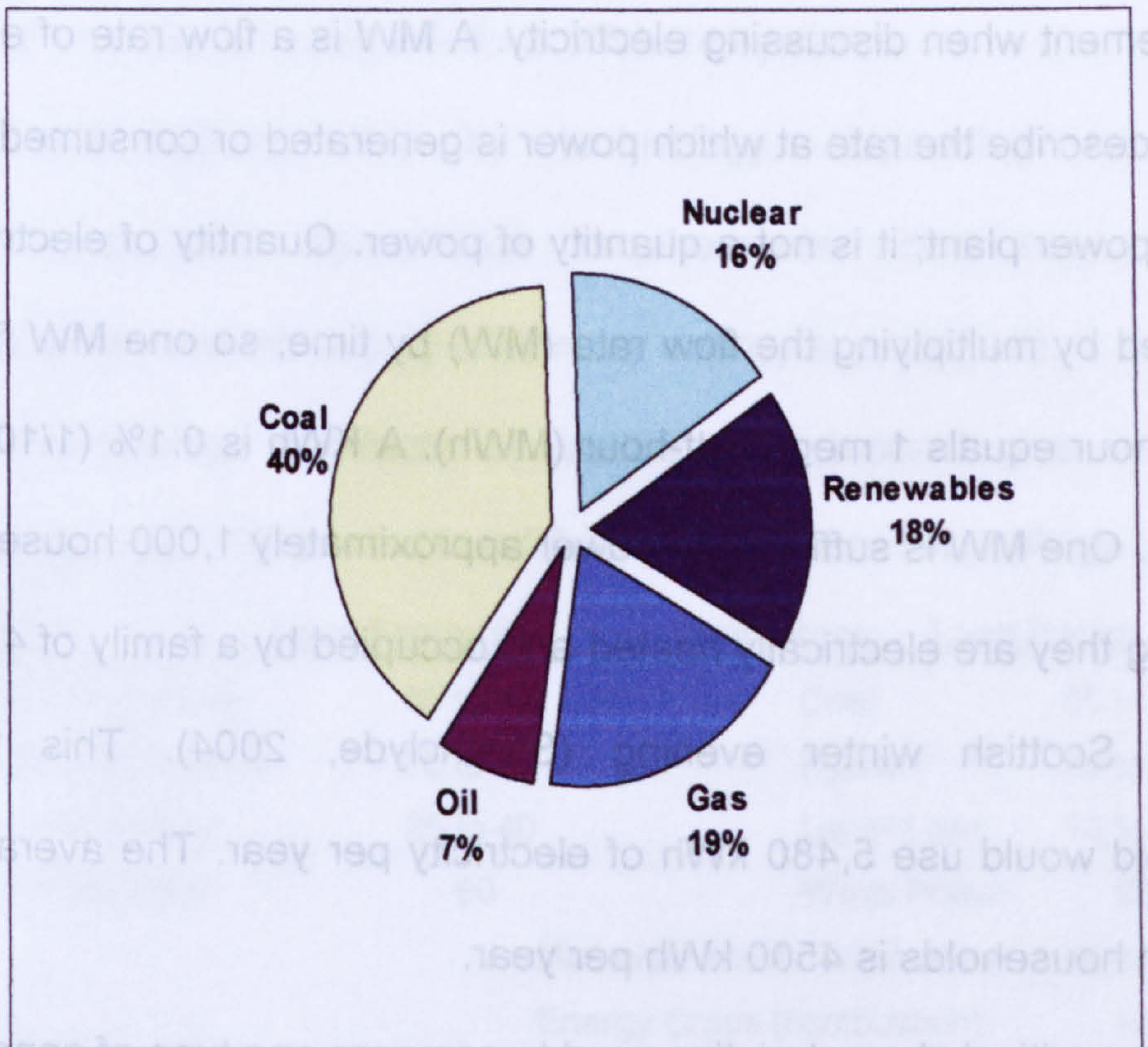
Energy, in the context of this thesis, refers to electric energy or forces of nature that are being used by humans to produce a mechanical force which moves a generator turbine and produce electricity for commercial distribution.

Renewable energy is a phrase that can be easily misconstrued. The author uses the phrase, "renewable energy", to describe the combination of technology and environmental resources that produce usable electric energy. The environmental resource must be capable of replenishment in human life and commercial time scales. Without this limitation even fossil fuels like oil and coal are "replenishable" over millions of years (ASE, 2005).

Most forces of nature which can be harnessed for renewable energy depend upon relatively new technologies which are not economically competitive or commercially viable at this time (UCS, 2004). This statement is not true for one type of renewable energy, hydroelectric power. Hydro is the single largest source of renewable energy in Scotland, the UK and the world (IEA, 2003; KSES, 2004). Hydroelectric generation is a mature technology that has production costs which compete with fossil fuels and nuclear power in most of the world.

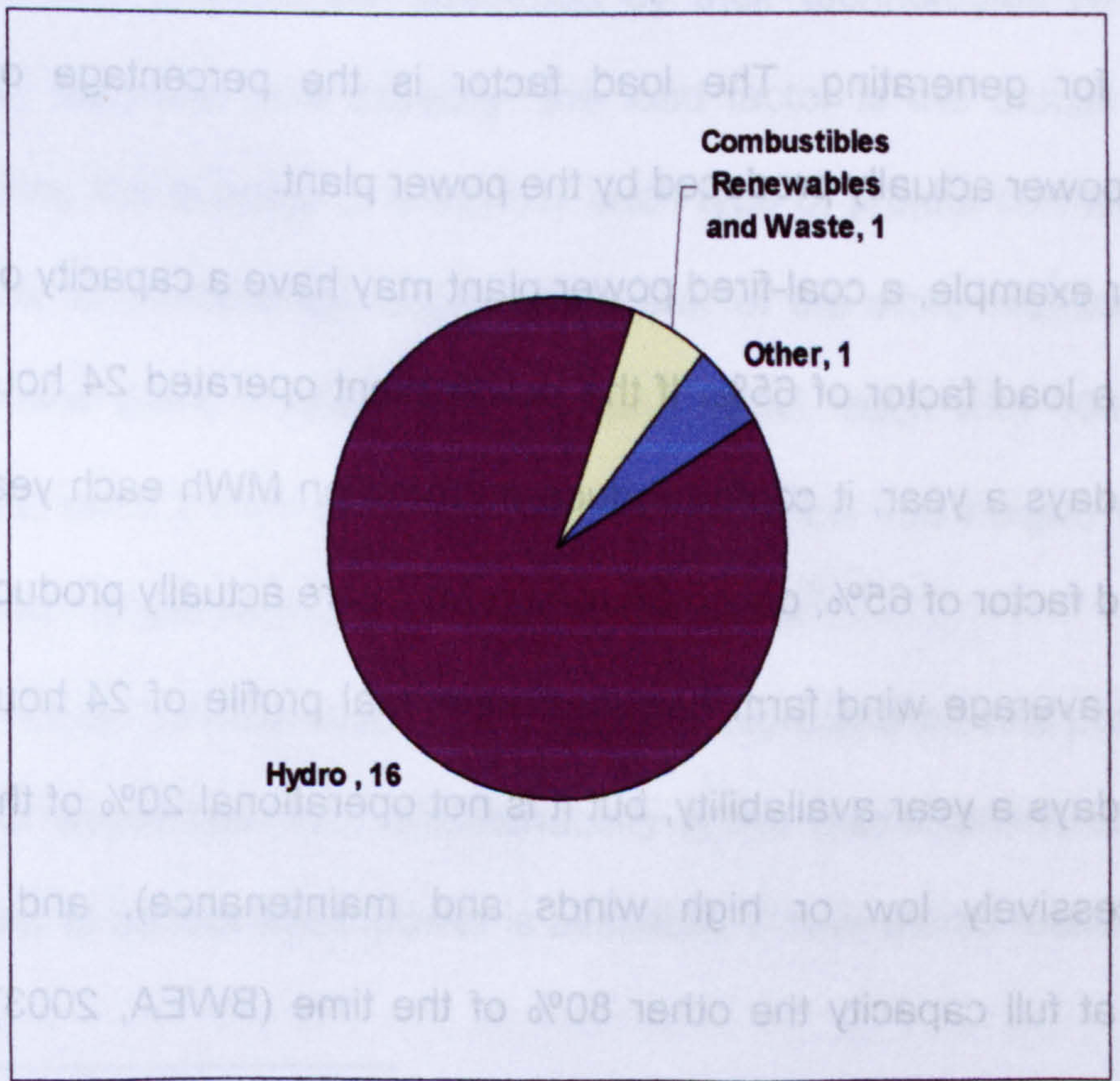
Electricity is an uncommon commodity, which is instantaneously consumed as it is produced. The fine balance between production and consumption must be maintained or the transmission and distribution system will experience blackouts (Cozassa, 2003). There is no slack in the system for the physical delivery of electricity.

**Chart 1.2** Global Sources of Electricity Production, 2003




(IEA, 2003)

**Chart 1.3** Global Sources of Renewable Electricity Production, 2003




(IEA, 2003)

Megawatt (MW) and kilowatt-hour (kWh) are standard units of measurement when discussing electricity. A MW is a flow rate of energy, used to describe the rate at which power is generated or consumed, i.e. a 50 MW power plant; it is not a quantity of power. Quantity of electricity is measured by multiplying the flow rate (MW) by time, so one MW flowing for one hour equals 1 megawatt-hour (MWh). A KWh is 0.1% (1/1000) of an MWh. One MW is sufficient to power approximately 1,000 households, assuming they are electrically heated and occupied by a family of 4 on an average Scottish winter evening (Strathclyde, 2004). This typical household would use 5,480 kWh of electricity per year. The average for all British households is 4500 kWh per year.

Two critical characteristics used to compare one type of generating plant or facilities to another are the facilities' capacity and load factor. Capacity is the maximum MW power which can be produce; its total potential for generating. The load factor is the percentage of total potential power actually produced by the power plant.

For example, a coal-fired power plant may have a capacity of 1000 MW with a load factor of 65%. If the power plant operated 24 hours per day, 365 days a year, it could produce 8.76 million MWh each year. But with a load factor of 65%, only 5.69 million MWh are actually produced[2].

An average wind farm has an operational profile of 24 hours per day, 365 days a year availability, but it is not operational 20% of the time (due excessively low or high winds and maintenance), and rarely operates at full capacity the other 80% of the time (BWEA, 2003). This

[2] 1000 MW * 24 hours * 365 days = 8,760,000 MWh.
8,760,000 MWh * 65% = 5,694,000 MWh.

means wind farms have an average load factor of 25% to 40%, the upper portion of the range is expected for offshore systems.

Load factors vary by technology, depending on repair, maintenance and operational requirements, consumer demand requirements, and the supply of primary energy source (fuel).

The average load factor by various power technologies:

**Table 1.1** **Expected Load Factors by Power Technology**

| Technology | Load Factor (%) | Technology | Load Factor (%) |
|---|---|---|---|
| Nuclear Power | 65 to 85 | Coal | 65 to 85 |
| CC Gas Turbine | 70 to 85 | Hydro | 30 to 50 |
| Wind Energy | 25 to 40 | Landfill gas | 70 to 90 |
| Sewage gas | 90 | Wave Power | 25 |
| | | Municipal Waste Combustion | 60 to 90 |
| | | Energy Crops (combustion) | 85 |

(AusWEA, 2004)

Power projects are described by their technologies (wind, coal, nuclear, etc.) and MW capacity, the load factor is the crucial factor in comparing the quantity of electricity each type of project can deliver. For example, to produce the equivalent power of the afore mentioned coal-fired power plant, it would take 20 wind farms, each with 100 MW (50 turbines, each 2 MW capacity, with a 100 metre hub height) at a 33% load factor to deliver the same quantity of power[3].

A final concept which is needed to understand electric power is the issue of dispatchability. Dispatchability is the characteristic of a power producer to control when power is available. Power plants fuelled by coal,

[3] 20 farms * 100 MW = 2000 MW. 2000MW * 24 hours * 365 days = 17,520,000 MWh. 17,520,000 MWh * 33% = 5,781,600 MWh.

methane and nuclear are totally dispatchable, as are biomass combustion plants (biomass combustion is classified as renewable). Hydroelectric is dispatchable, if water has been stored in controlled reservoirs. Marine based renewable technologies are not dispatchable, but are highly predictable. Wind and run of river hydro are not dispatchable.

Society, households and business firms, in economically developed counties generally plan on electric power being available whenever it is demanded by them. Therefore, the less controllable or dispatchable an energy technology is the less value it has compared to power from traditional sources (UCS, 2004).

**Electric Power in Scotland (Current Profile)**

Slightly less than 50 million MWh of electricity was generated is Scotland in 2002. Approximately two-thirds of this amount, 33.6 million MWh, was consumed within the Scottish economy. The remaining one-third is accounted for by transmission and distribution losses, own use by power producers, pumped hydro-storage facilities, and net transfers to England, Wales and Northern Ireland (KSES, 2004). Demand growth in Scotland has averaged 0.79% per year during the past 10 years, while growth in supply has averaged 2.24% per year for the same time period (SEEF, 2003). To maintain the balance between generation and consumption, an increasing amount of power is being transmitted (exported from Scotland) to England and Wales for consumption.

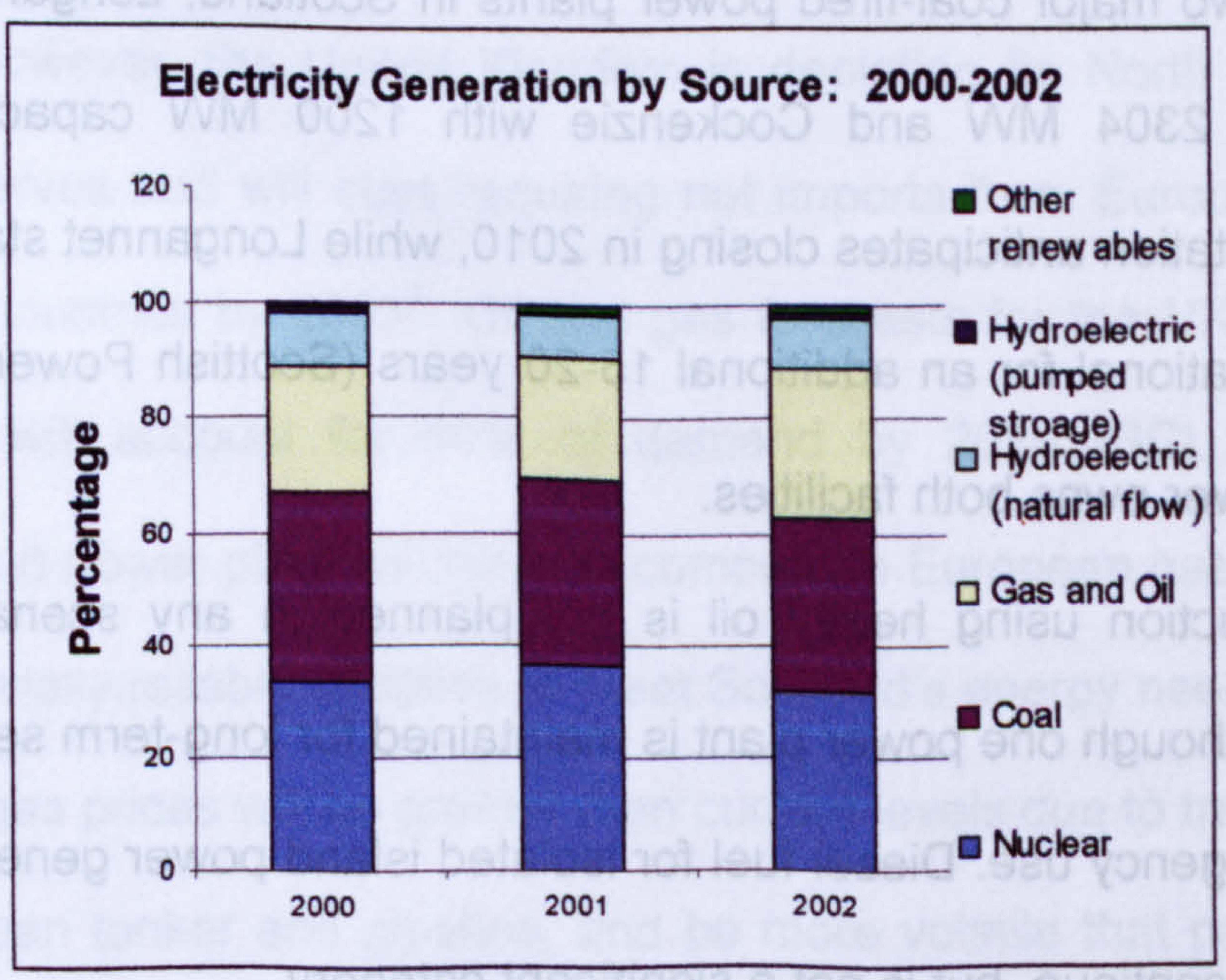
**Table 1.2** **Scottish Electricity Generation and Consumption: 2001-2002**

| | GigaWatt hours (GigaWatt = 1000 MWh) | | |
|---|---|---|---|
| | **2000** | **2002** | **2002** |
| Electricity Consumed | 34,690 | 33,840 | 33,680 |
| Other uses or loss | 15,681 | 15,128 | 15,875 |
| Total electricity generated | **50,731** | **48,968** | **49,555** |

(KSES, 2004)

Scotland's percentage of consumption will rise dramatically in 2004 and beyond as the national level of production decreases. This decrease is the result of power station closures in Scotland. British Nuclear Fuels Limited ordered the Chapelcross Nuclear Power Plant to cease operation in June 2004 (BNFL, 2004). All power produced at Chapelcross was exported to England and Wales. The remaining two nuclear power plants in Scotland, Torness and Hunterston B, are scheduled for closure in 2021 and 2011, respectively (DTI,2004). Both stations are owned by British Energy. Together

**Chart 1.4** **Scottish Electricity Generation by Source: 2000-2002**




(KSES, 2004)

**Table 1.3** Scottish Electricity Generation by Source: 2000-2002

| | Percentage | | |
|---|---|---|---|
| | 2000 | 2001 | 2002 |
| Nuclear | 33.6 | 36.9 | 32.0 |
| Coal | 33.3 | 32.2 | 30.8 |
| Gas and Oil | 22.0 | 21.2 | 25.6 |
| Hydroelectric (natural flow) | 9.3 | 7.6 | 9.0 |
| Hydroelectric (pumped storage) | 1.2 | 1.1 | 1.3 |
| Other renewables | 0.6 | 1.0 | 1.3 |

(KSES, 2004)

The three nuclear power stations operating in Scotland produce one-third of the power generated in Scotland. These nuclear facilities also supplied the energy used for pumped hydroelectric storage at the Cruachan and Foyers power stations (Scottish Power, 2004).

Fossil fuels contributed over one-half of the primary energy sources for generating electricity during the years 2000-2002. Coal, with a 32% share, contributes more GHG emissions per unit of electricity delivered than any of the other energy sources (EIA, 2004). Natural gas produces 60% less GHG per MWh of production than coal (EC, 2004). There are two major coal-fired power plants in Scotland; Longannet with capacity of 2304 MW and Cockenzie with 1200 MW capacity. The Cockenzie station anticipates closing in 2010, while Longannet station will remain operational for an additional 15-20 years (Scottish Power, 2003). Scottish Power owns both facilities.

Production using heavy oil is not planned in any scenarios for Scotland, although one power plant is maintained for long-term security of supply emergency use. Diesel fuel for isolated island power generation is expected to continue, but is not a significant category.

The last large scale power project to mention in Scotland is located in Peterhead and is owned by Scottish and Southern Energy. The Peterhead Power Plant is a natural gas-fired power plant with a 2500 MW capacity. It is expected to operate past the year 2030. A 400 MW natural gas-fired station has been approved for construction in Fife, but no construction start or commissioning date has been announced (DUKES, 2003).

Scotland will experience a major restructuring of its electric power system over the next 20 years. Hunterston B and Cockenzie, with 28% of Scotland's capacity, will close by 2011. Longannet and Torness, with 42% capacity, will close in 20 years. 70% of current generating capacity will need to be replaced if Scotland is to remain a net exporter of power.

In excess of 50% of new capacity will need to be constructed within Scotland if it is to continue being self-sufficient in supplying its own power demands. Only one major facility will not need replacement, the Peterhead Power Station.

However, the United Kingdom is depleting its North Sea natural gas reserves and will start requiring net imports from Europe and other foreign countries by 2005[4]. Oil and gas forecasts for the UK predict gas imports will account for 50% of demand by 2010 (SCI, 2004). The Peterhead power plant will have to compete in European gas markets for commercially reliable supplies to meet Scotland's energy needs. Imported natural gas prices will be greater than current levels due to transportation, both ocean tanker and pipeline, and be more volatile that past domestic

[4] The transition from being a net exporter to a net importer did occur as predicted in the 3rd quarter of 2005 (IEA, 2006)

supplies have been. Winter prices are forecasted to trade around 24 pence per therm (approximately 100 cubic feet of gas) by 2004-6[5] as compared to 21 pence per therm, a 15% price increase (SCI, 2004).

Renewable energy sources made up the smallest portion of energy production in Scotland, having grown to just over 10% of total electric energy supplied in 2002. Long established large and medium scale hydroelectric schemes provide 9/10th of this category. Large and medium scale hydroelectric schemes are a mature technology and have been commercially competitive with nuclear and fossil-fuelled generation for many decades (BHA, 2004). However, expansion possibilities are very limited in Scotland as most all sites for large hydro schemes have already been developed during the past century. Only one project in excess of 12 MW capacity is currently being analysed for construction, the 100 MW Glencoe Hydro project beside Lock Ness (SE, Section 36, 2004).

**The Changing Profile**

It is the in the "Other Renewables" category that is of particular interest to the author. As seen in the above Table 1.3, there has been a doubling of electricity derived from new types of renewable energy within just 2 years, 2000-2002. This rate of growth is expected to continue at even higher rates given the new structure of government regulation and the resulting economic profits being earned by renewable energy power firms. Chapter Two discusses the effects of the new policies in detail.

[5] Price per therm in winter 2006 was 28 pence (DUKES, 2006).

Prior to December 2002 no commercial scale (greater than 1MW capacity and connected to the electric grid) renewable generation systems of any technology type had been commissioned in Scotland using solely private funds. All projects had received capital grants from local councils and the national government or higher than market prices for electricity through government subsidies.

**Renewable Energy Policy and Programs in other European Countries**

This section begins by discussing three keystone international agreements that act as exogenous motivators for renewable energy development in the United Kingdom and Scotland. The first is the United Nations Framework Convention on Climate Change and its companion implementation agreement, The Kyoto Protocol. The third agreement is the European Union Directive on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market. After which common national policies and programs used to support the deployment of renewable energy systems are described.

United Nations Framework Convention on Climate Change and the Kyoto Protocol

The United Nations Framework Convention on Climate Change (UNFCCC) in 1992 established a process for agreeing to specific actions at a later time (UN, 2003). Essential issues that were agreed upon in the climate change convention are:

i. There is a global environmental problem with increasing concentrations of climate change gasses and increasing rates of emissions.

ii. An ultimate goal of stabilizing climate change gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the global climate.

iii. Achieve stabilization of climate change gasses within a timeframe that allows for adaptation by ecosystems and human society.

There are several explicit value judgments about how the work of the climate change convention should go forward:

i. Poorer nations have a right to economic development.

ii. The greatest vulnerability from climate change is placed upon the poorer nations.

iii. The responsibility and costs for avoiding climate change are to be carried by the rich developed nations.

The rational for the value judgements stated in the convention are that developed nations have put most of the climate change gasses in the atmosphere to date and are the primary ongoing contributors. Sifting agricultural zones, sea level rise, and rainfall patterns changes all effect developing nations more than developed nations.

The Kyoto Protocol was adopted in 1997 by the UNFCCC in response to the growing scientific information and public pressure about responding to global climate change. It is considered the most far reaching agreement on environmental and sustainable development ever adopted. The Protocol has three significant items:

i. Legally binding targets and time tables for member nations to comply with the Protocol.
ii. Six climate change gasses were identified as the emissions to be reduced. Three major gasses: carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). Three industrial gasses: Hydrofluorocarbons (HFCs), Chlorofluorocarbons (CHCs), and sulphur hexafluoride ($SF_6$).
iii. The emissions reductions of each nation are to be verifiable and credible.

The over arching objective is for a 5.2 % reduction in aggregate emissions below the 1990 levels by 2008-2012. The reduction in atmospheric pollution rates will not be sufficient to reduce the existing stocks of climate change gasses but will slow down the rate of increase in pollution.

The Kyoto Protocol is expected to enter into full legal force worldwide in November 2004 after Russia formally ratifies the agreement. (Reuters, 2004) To become international law the protocol had to be ratified by Annex 1 (UN, 2003) listed nations, which consists of developed nations participating in the UNFCCC. These ratifying nations have to account for at least 55% of the GHG emissions from the developed nations. Russian, with 17% of GHG emissions, became critical for the protocol to be enacted when the United States withdrew in 2001. Russia represents 17% of the emissions and the United States contribution is 36%.

Table 1.4 **Annex I Party carbon dioxide emissions in 1990****

| Party | 1990 $CO_2$ emissions (Mmt) | % |
|---|---|---|
| Australia | 288.97 | 2.1 |
| Austria* | 59.20 | 0.4 |
| Belgium* | 113.41 | 0.8 |
| Bulgaria | 82.99 | 0.6 |
| Canada | 457.44 | 3.3 |
| Czech Republic | 169.51 | 1.2 |
| Denmark* | 52.10 | 0.4 |
| Estonia | 37.80 | 0.3 |
| Finland | 53.90 | 0.4 |
| France* | 366.54 | 2.7 |
| Germany* | 1012.44 | 7.4 |
| Greece* | 82.10 | 0.6 |
| Hungary | 71.67 | 0.5 |
| Iceland | 2.17 | 0.0 |
| Ireland* | 30.72 | 0.2 |
| Italy* | 428.94 | 3.1 |
| Japan | 1173.36 | 8.5 |
| Latvia | 22.98 | 0.2 |
| Liechtenstein | 0.21 | 0.0 |
| Luxembourg | 11.34 | 0.1 |
| Monaco | 0.07 | 0.0 |
| Netherlands* | 167.60 | 1.2 |
| New Zealand | 25.53 | 0.2 |
| Norway | 35.53 | 0.3 |
| Poland | 414.93 | 3.0 |
| Portugal | 42.15 | 0.3 |
| Romania | 171.10 | 1.2 |
| Russian Federation | 2388.72 | 17.4 |
| Slovakia | 58.28 | 0.4 |
| Spain* | 260.65 | 1.9 |
| Sweden* | 61.26 | 0.4 |
| Switzerland | 43.60 | 0.3 |
| United Kingdom* | 584.08 | 4.3 |
| United States | 4957.02 | 36.1 |
| | Mmt = million metric tonnes | |
| * European Union members states combined | | 24.2 |
| Individual country's share of the total global $CO_2$ emissions for the purpose of determining entry into force of the Kyoto Protocol.<br><br>The table does not include Annex 1 Parties that had not yet submitted a national communications under the Convention when the Protocol was adopted. The emission of these Parties (Croatia, Lithuania, Slovenia and Ukraine) will not be counted towards the entry into force threshold. Figures exclude the land-use change and forestry sector. | | |

(CCS, 2002)

European Union Directive on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market

In 2001 the European Union issued after long discussions between the different institutions the Directive on the promotion of electricity produced from renewable sources (RES-E directive). This Directive sets out to create a framework that will promote, in the medium term (10 years), a significant increase in renewable electricity within the EU. It represents an important way point in shaping the regulatory framework for RES-E generation in the EU. The RES-E Directive might even be a prelude to a possible EU-wide harmonisation of regulations at Member State level. Hereafter the main features of the RES-E Directive are outlined (EUFORES, 2005).

The Directive set a target of 22.1% of renewable electricity as compared to overall electricity consumption should be met by 2010. In the Annex the European target are transformed into targets for the Member States.

The RES-E Directive provides for a broad definition of renewable energy. It includes hydro power (large and small), biomass (solids, biofuels, landfill gas, sewage treatment plant gas and biogas) wind, solar (PV, heat, thermal electric), geothermal, wave and, tidal energy. General waste incineration has been excluded but the biodegradable fraction of waste can be considered as renewable. A contentious category, the biodegradable part of waste incineration, is allowed 'as long as the waste hierarchy is respected' has been retained. Furthermore, large hydropower (more than10 MW) is also included. It has been tacitly agreed that large hydro will count for meeting the targets but will not be eligible for support measures.

**Table 1.5** **Renewable Electricity Targets for EU Member States**

| | **Member States** | |
|---|---|---|
| | RES-E % 1997 | RES-E % 2010 |
| Belgium | 1.1 | 6.0 |
| Denmark | 8.7 | 29.0 |
| Germany | 4.5 | 12.5 |
| Greece | 8.6 | 20.1 |
| Spain | 19.5 | 29.4 |
| France | 15.5 | 21.0 |
| Ireland | 3.6 | 13.2 |
| Italy | 16.0 | 25.0 |
| Luxembourg | 2.1 | 5.7 |
| Netherlands | 3.5 | 9.0 |
| Austria | 70.0 | 78.1 |
| Portugal | 38.5 | 39.0 |
| Finland | 24.7 | 31.5 |
| Sweden | 49.1 | 60.0 |
| United Kingdom | 1.7 | 10.0 |
| Community | 13.9 | 22.0 |
| | **New Member States** | |
| | RES-E % 1999 | RES-E % 2010 |
| Cyprus | 0,05 | 6 |
| Czech Republic | 3,8 | 8 |
| Estonia | 0,2 | 5,1 |
| Hungary | 0,7 | 3,8 |
| Latvia | 42,4 | 49,3 |
| Lithuania | 3,3 | 7 |
| Malta | | 5 |
| Poland | 1,6 | 7,5 |
| Slovenia | 29,9 | 33,6 |
| Slovakia | 17,9 | 31 |
| Community | 12,9 | 21 |

(RES-E, 2003)

It is important to note that the directive does not present a harmonised European support scheme. The member states are obliged to fulfil their own clearly specified national targets, which vary greatly. An EU-wide negotiation agreed to these targets. And at the same time, the principles providing for these national targets for consumption of electricity from renewable sources of energy are defined at the Community level, i.e. the ground for a future efficient and effective EU-wide system is being prepared.

The grid access issue is another important point of the directive. Concerning the issue of the high costs of grid connection, the directive requires member states to take the necessary measures to grant guaranteed access to the transmission and distribution of electricity from renewable energy sources. Where appropriate member states have to give priority access to renewable energy sources. All over Europe, network operators will be obliged to set up transparent cost calculations for distribution and the fees have to be non-discriminatory. A further improvement is that the grid capacity is no longer a reason not to give access. The grid operators have to reinforce their grid if necessary for the connection.

Member States will ensure that operators:

Publish objective, transparent and non-discriminatory rules on costs for connection and for strengthening of the grid provide producers with complete and detailed estimates of costs. The grid operator can only deny grid access with regards to the maintaining the reliability and safety of the grid. Unfortunately many grid operators are relying on this while denying grid access.

Moreover, the directive addresses the particular problem of lengthy and difficult administrative procedures that potential generators of renewable energies must respect in many member states. It requires them to review their existing legislative and regulatory frameworks in order to speed up authorisation procedures.

The objectives of the member states are:

- to reduce the obstacles to increasing production
- to rationalise and speed up administrative procedures
- to ensure objective, transparent and non-discriminatory rules
- to take account of the characteristics of renewable technologies

The directive also provides for a system concerning the guarantee of origin of renewable energies, which will increase transparency while facilitating consumer choice.

And finally, this directive gives the Commission an instrument with which it will be able to assess the level-playing field of the electricity market thoroughly for the first time. The state aid in the member states' conventional energy sources sectors will be subject to strict evaluation. And apart, the commission has to evaluate the success made in reflecting the external costs of conventional energy sources.

### Common Policies to Support Renewable Energy

Currently, there are a range of government programs and support systems for renewable energy expansion being used by European Union countries. These programs can be classified into four broad groups: feed-in tariffs, quota obligations (tradable green certificates), tendering systems and tax incentives. The following policy descriptions are taken from "The support for electricity from renewable energy sources impact assessment", a report from the European Commission (EC, 2005).

Feed-in tariffs (renewable energy feed-in tariff or REFIT) are the most common financial support program in the EU, with a majority of Member States using this policy. Feed-in-tariffs are a guaranteed market price for green energy producers; the price is set by the government for electricity derived from specific sources or technologies.

Feed-in-tariffs have several advantages: investment security for developers and investors, fine tuning of support to specific technologies, as well as the promotion of mid- and long-term technologies, not just technologies which are on the cusp of commercial viability. However, feed-in-tariffs are difficult to harmonize with other countries if an EU-wide support program is to be created. A more market-oriented variant of the feed-in-tariff is the support premium, where a predetermined monetary subsidy is paid in addition to the revenues earned from fluctuating electricity prices. This later REFIT system is operating in Denmark and in Spain. Spain uses this market price plus top up premium to support specific technologies.

Green certificates (Tradable Green Certificates or TGCs) are market-based instruments. Green energy producers are given certificates to match their production of electricity and end users or other power market agents are required to purchase the certificates to meet government mandates. At least in theory, TGC programs have the advantage of yielding the best value for money invested, and the program favours a single European market while posing a lower risk of over-compensation. However, green certificates create a higher risk for investors and early stage technologies may not receive sufficient financial premiums to be supported under such schemes. The United Kingdom has used a TGC program since 2002.

Pure tendering procedures have been used by Ireland and France. Tendering programs consist of the governments contracting private firms to build and operate renewable power facilities of a specific size and technology. France recently changed its support system to a combination of tendering and feed-in-tariff. Ireland is moving in the same policy direction. Theoretically, tendering systems make optimum use of market forces, but they behave in a stop-and–go manner and are not conducive to stable investment conditions. This type of support scheme involves the risk that low bids may result in projects not being implemented. This was the program used in Scotland (Scottish Renewables Order[6]) and throughout the UK during the 1990's.

[6] Scottish Renewables Order is discussed elsewhere in this chapter.

Pure tax incentives are applied in Malta and Finland. In most cases (e.g. Cyprus, UK and the Czech Republic), however, this instrument is used as an additional policy tool.

It should again be emphasized that the above categorization into four groups is a fairly simple presentation of the situation. There are several national schemes that have mixed elements, especially in combination with tax incentives.

**Renewable Energy Support Programs in other European Countries**

Four European countries are profiled in this section; Germany, Spain, Sweden and Denmark. These countries have been operating under the same goals and external commitments of the Directive for Renewable Energy Sources – Electricity and The UNFCCC and Kyoto Protocol. Brief commitments are made comparing experiences with Scotland and possible lessons which can be learned. The following profiles have been substantially taken from "Country Profiles: Overview of Renewable Energy Sources in the Enlarged European Union", a report written for the European Commission in "004 (EC, 2004).

**Germany**

Germany has experienced dramatic growth in renewable energy during the last decade as a result of an aggressive government subsidy program. Wind energy has grown faster than any other power generating source, in absolute quantity, not just in proportional growth. In 2003 wind farms in Germany contributed the same level of power production as the large and small hydropower sector, approximately 25,000,000 MWh.

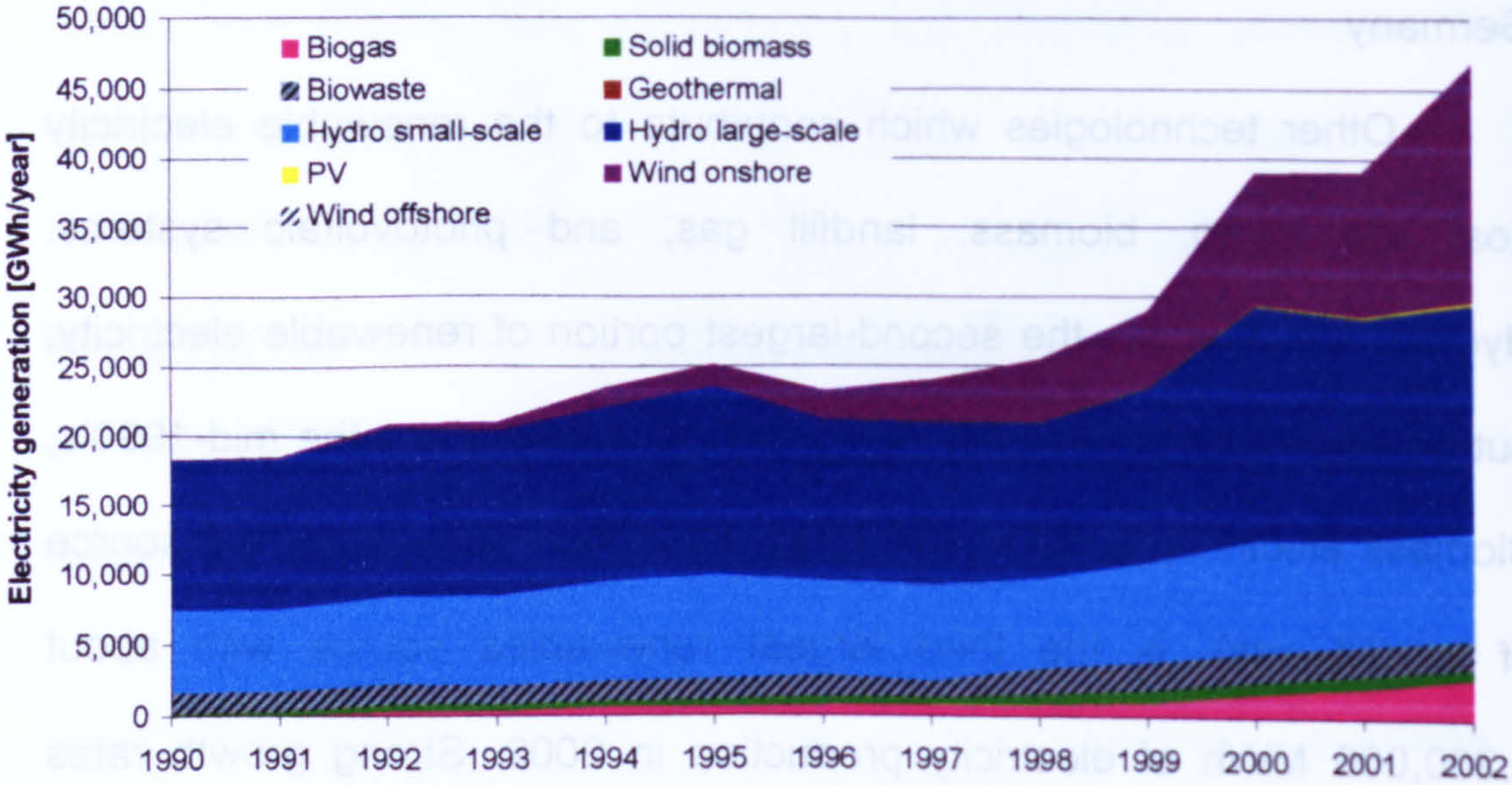
About 50% of Europe's wind energy generating capacity is installed in Germany.

Other technologies which contribute to the renewable electricity goal are hydro, biomass, landfill gas, and photovoltaic systems. Hydropower provides the second-largest portion of renewable electricity, but no significant new deployments have occurred since the mid-1990's. Biomass electricity (including biodegradable municipal waste, the source of landfill gas), is the third largest renewables source with about 6,200,000 MWh of electricity production in 2002. Strong growth rates have also been achieved with photovoltaic systems, with installed capacity of 258 MW and a generating potential of about 190,000 MWh in 2002 and about 260,000 MWh in 2003.

Actual power generation from 1990 until 2002 is shown in Table 1.5. Two facts to notice in the chart are; total power production is up from approximately 18,500 GWh to 47,000 GWh in 2002, a 155% increase in production, and observe that wind and hydropower were both lower in 2001 than is 2000, as a result volatile weather patterns. The average quantity of wind and rain were lower in 2001 than in 2000 leading to decreased energy production. This was in spite of an expansion in the number of deployed wind turbines.

A similar weather event occurred in 2003 with actual generation of wind energy being lower, decreased to 18.5 TWh, due to seasonal wind speeds and duration being 16% below average.

**Graph 1.1** **RES electricity production up until 2002 in Germany**




(EC, 2004)

In Table 1.6 renewable electricity generation is shown for the years 1997 and 2002 as well as the average annual growth during this period.

**Table 1.6** **RES-electricity production in 1997 and 2002 in GWh**

| RES-E Technology | 1997 {GWh] | 2002 [GWh] | Av. Annual growth [%] |
|---|---|---|---|
| Biogas | 746 | 2,913 | 31% |
| Solid Biomass | 505 | 700 | 7% |
| Biowaste | 1,168 | 2,035 | 12% |
| Geothermal electricity | 0 | 0 | |
| Hydro large-scale | 11,696 | 16,340 | 7% |
| Hydro small-scale | 6,772 | 7,660 | 2% |
| Photovoltaics | 27 | 176 | 45% |
| Wind onshore | 3,034 | 17,200 | 41% |
| **Total** | **23,948** | **47,024** | **14%** |
| Share of total consumption [%] | 4.50% | 8.1% | |

(EC, 2004)

**RES targets**

The RES-E target set for Germany to be achieved in 2010 is 12.5% of gross electricity consumption (in 2020 10% of total energy consumption and 20% of electricity consumption).

**Status of the renewable energy market**

Germany has a mature renewable energy market which is showing large growth rates even at high market share rates. Biomass is the only technology that is significantly lagging behind expectations.

**Main supporting policies**

The main promotion scheme for renewable energy in Germany is the Renewable Energy Act. This legislative act creates a program of renewable electricity feed-in tariffs[7]. This act is due to be updated to reflect the maturity of some technologies which will need less support and the desire to incentivise expansion of other technologies like biomass

Current renewable electricity feed-in-tariff subsidies (2003):

- Wind: 9 € cents/kWh for at least five years after installation. Reduction of tariff to 6 € cents/kWh depending on yield of system. Yearly reduction of tariff by 1.5%.
- Biomass: up to 500 kW: 10 € cents/kWh, up to 5 MWp: 9 € cents/kWh, up to 20 MWp: 8.6 € cents/kWh,
- Hydro, landfill gas, sewage gas: up to 500 kW: 7.7 € cents/kWh, form 501 kW to 5 MW: 6.6 € cents/kWh

[7] See prior section on Renewable Energy Support Policies.

- PV: 48 € cents/kWh, yearly reduction of tariff by 5%.

  Starting in January 2004 feed-in-tariff of 59 € cents/kWh.

Market Incentive Program: Investment subsidy for most sources except wind.

Income tax regulations on wind energy investments.

Environment and Energy Efficiency Program: subsidized loans for major share of wind investments.

Full exemption from mineral oil tax and environmental tax for all pure liquid and solid biofuels in heat and transport.

**Key factors**

Limited grid capacity in the northern parts of Germany is currently hampering the growth of onshore wind energy. This constraint is resulting in limited exploitation of wind generating potential. Offshore wind energy is deploying more slowly than predicted due to higher than expected costs and technical problems (long distance from land and deep water). Biomass combustion is deploying slower than expected due to fuel price uncertainty and high infrastructure costs. The use of low-cost wood waste, i.e., forest slash has been fully exploited, so more expensive biomass sources must be developed.

The proposed new renewable energy act will have a major impact on wind, biomass and large hydropower. The current high feed-in tariffs, investment subsidies and government loans have facilitated considerable growth in the renewables market.

A new feed-in tariff system is proposed that will lower the tariffs for wind on-shore, increase tariffs for biomass electricity, geothermal electricity and introduce a feed-in tariff for the refurbishment of large hydro. The reallocations of resources provided by the government due to new priorities for renewable technology are predicted to motivate minor restructuring of the renewables market.

The stability of political support and policy regimes in Germany has successfully stimulated continuous and high levels of growth in renewable energy, especially in the case of wind energy, PV and solar thermal installations over the past decade.

**In comparison to Scotland:**

Germany has attained dominance in installed wind power capacity whilst having a lesser amount of the natural resource. Scotland has about one-half of the wind resource of all Europe, yet has less than one-sixth the capacity of Germany, at the present time.

The consistent and clear support from the German government of almost a decade has created a positive investment climate in renewable technologies. The feed-in-tariff has shown itself to be very low risk for investors.

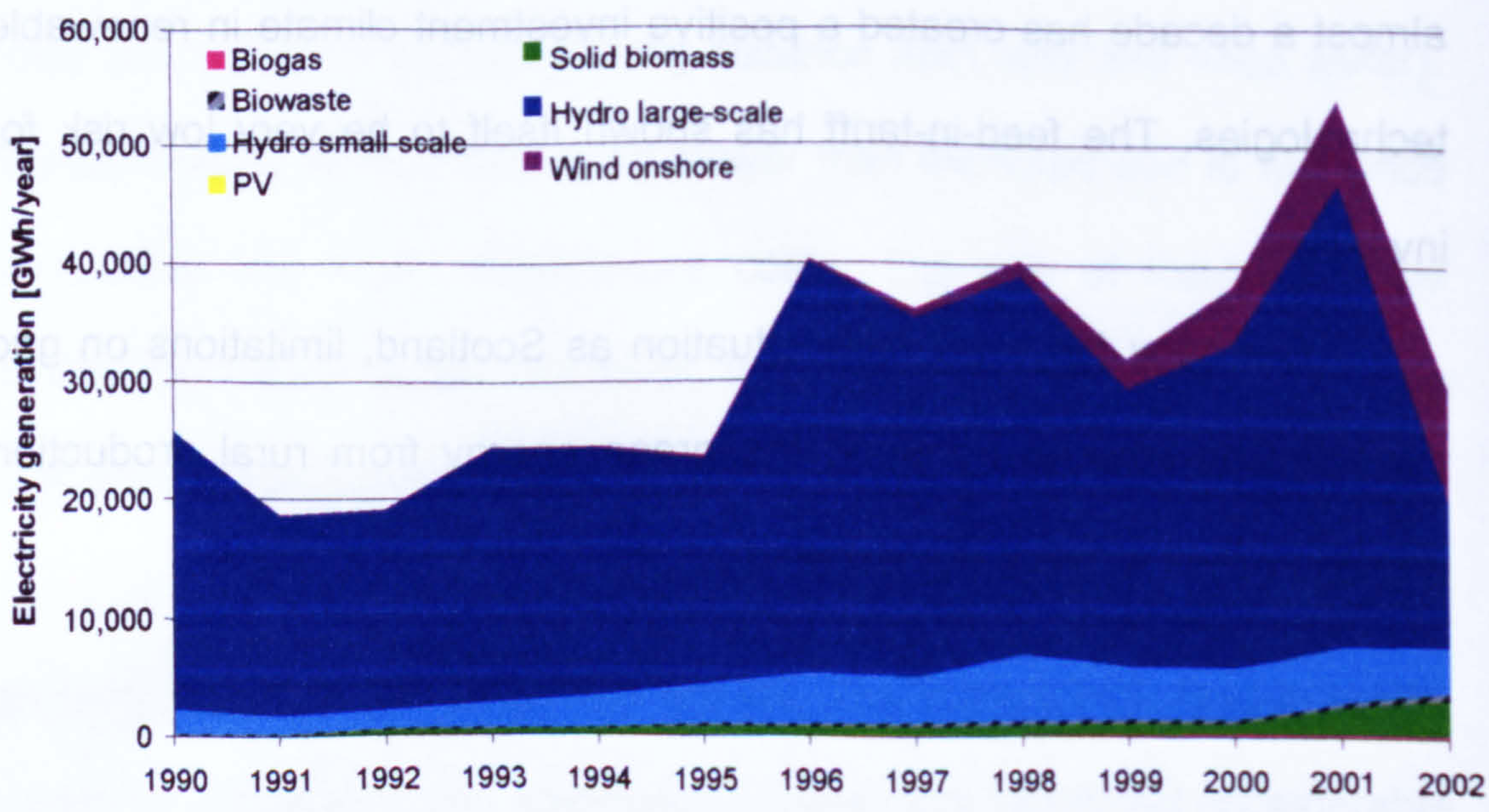
Germany faces a similar situation as Scotland, limitations on grid transmission lines to transport the green energy from rural production areas to areas with greater demand.

**Spain**

Hydropower is by far the most significant source of renewable energy in Spain, contributing approximately 16,000,000 MWh in 2002, representing 41% of all renewable power produced that year. Strong growth in on-shore wind farms has occurred during the past decade. Spain achieved 4,100 MW of wind farm capacity by the end of 2002 and more than 6,000 MW by the end of 2003, a 50% expansion in one year. The capacity level is similar to the total wind capacity within the United States in 2002. Spain benefited from 9,600,000 MWh of wind energy in 2002.

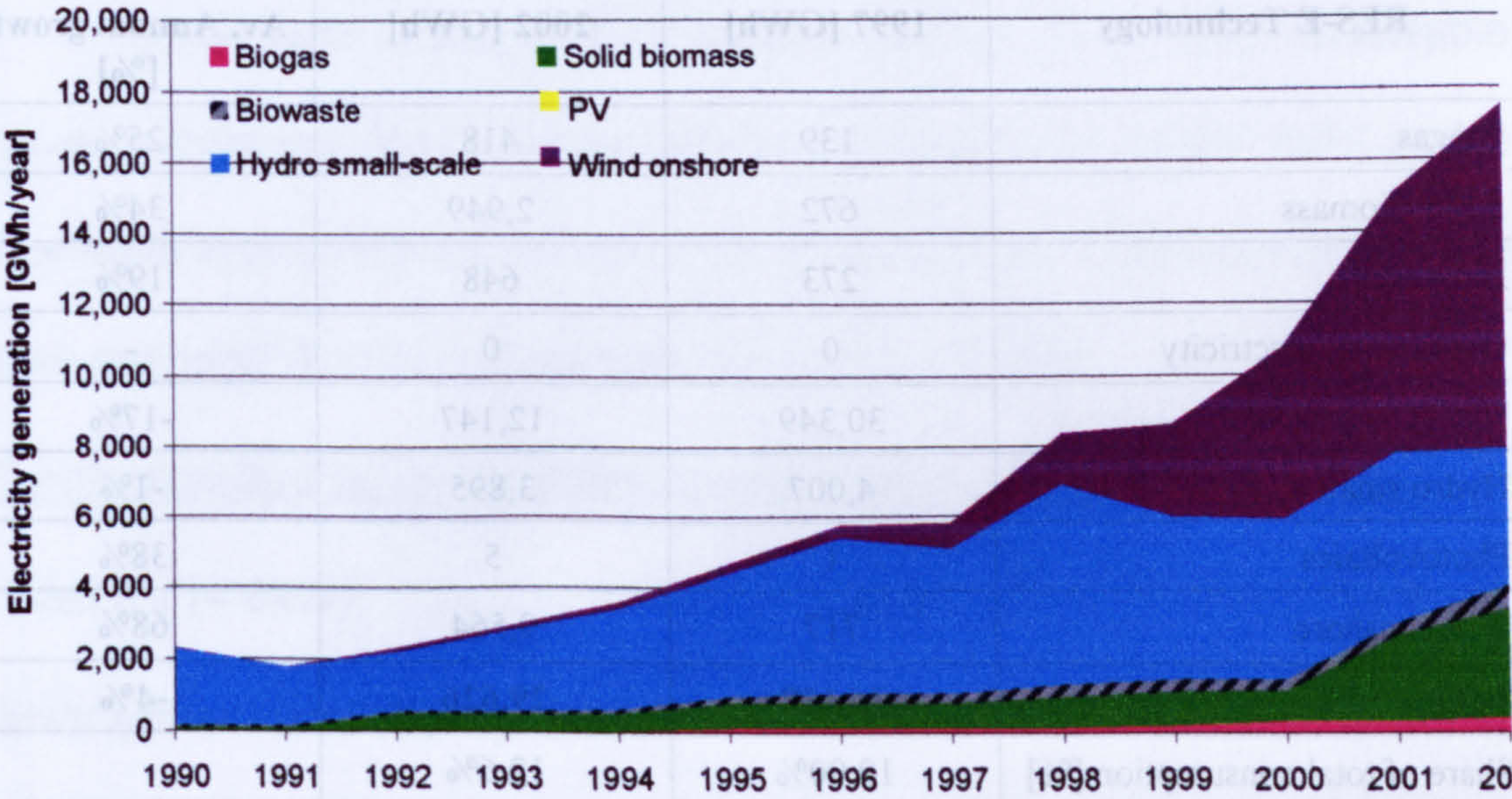
Solid biomass is also relatively well developed with 8%, 2,900,000 MWh, of total renewable power being generated from this technology in 2002.

<u>Graph 1.2</u> **RES-electricity production up until 2002**




(EC, 2004)

**Graph 1.3 RES electricity production in Spain up until 2002 without large hydro**




(EC, 2004)

Table1.7, below, shows an overview of the electricity generation from renewable energy sources in Spain in 1997 and 2002, as well as the average annual growth during the intervening period. The electricity generation from RES expressed as share of the overall electricity consumption was 20% in 1997, while it was only 16.2% in 2002.

**Table 1.7** RES electricity production in 1997 and 2002 in GWh

| RES-E Technology | 1997 [GWh] | 2002 [GWh] | Av. Annual growth [%] |
|---|---|---|---|
| Biogas | 139 | 418 | 25% |
| Solid Biomass | 672 | 2,949 | 34% |
| Biowaste | 273 | 648 | 19% |
| Geothermal electricity | 0 | 0 | - |
| Hydro large-scale* | 30,349 | 12,147 | -17% |
| Hydro small-scale* | 4,007 | 3,895 | -1% |
| Photovoltaics | 1 | 5 | 38% |
| Wind onshore | 717 | 9,564 | 68% |
| **Total** | **36,158** | **29,626** | **-4%** |
| Share of total consumption [%] | 19.90% | 12.6% | |
| Non-large hydro RES-E | 5,809 | 17,479 | |

Spain uses a definition for small and large-scale hydro power capacity that is different from the commonly adopted EU definition. In Spain all production capacity lower than 50 MW is considered to be small-scale production capacity.

(EC, 2004)

## SUMMARY OF RENEWABLE ENERGY MARKETS AND POLICY

### RES targets

The RES-E goal set for Spain is 29.4% of gross electricity consumption to be met by renewables in 2010.

### Status of the renewable energy market

Wind power has expanded in a dramatic manner with 50% growth in 2002, as previously mentioned. The biomass sector needs an integrated policy approach which recognises the additional benefits for environmental protection and rural development.

**Main supporting policies**

Spain uses a feed-in-tariff support system, from which renewable power producers may choose between a fixed preferential tariff and a (variable) premium price on top of the market price. Investment support is also provided. Tariffs are specified for plants ≤ 50MW.

| Tariffs specified for 2003: | premium (€ct/kWh) | feed-in (€ct/kWh) |
|---|---|---|
| Solar PV (< 5kW): | 36.0 | 39.6 |
| Solar (other installations): | 18.0 | 21.6 |
| Solar thermal-electric: | 12.0 | |
| Wind: | 2.66 | 6.21 |
| Small Hydro (≤ 10MW): | 2.94 | 6.49 |
| Primary Biomass: | 3.32 | 6.85 |
| Secondary Biomass: | 2.51 | 6.05 |
| Geothermal, wave and tidal: | 2.94 | 6.49 |

(EC, 2004)

**Key factors**

- Transparent support schemes and the high feed-in tariffs deliver high investment certainty.
- Feed-in tariffs are decreased and might become too low to induce new investments.
- Changes due to liberalisation of the sector cause uncertainty.

- Biomass feed-in tariffs were up-to-now too low to develop new capacity.

Spain introduced a widespread and aggressive program to stimulate renewable energy deployment in 1997. This has resulted in substantial expansion in new capacity, primarily wind power. Feed-in tariffs and premiums provided high transparency and certainty for commercial developers and investors in the market and are therefore the principle motivators for the growth which has resulted to date. After Germany, Spain is the most favourable country for wind investments.

**In comparison to Scotland:**

Spain has chosen the feed-in-tariff mechanism for its primary support of renewable energy expansion. Dramatic growth occurred as a result as seen in the expansion of wind power. As with Germany this demonstrates the strength of feed-in-tariffs for the ability to target specific technologies and to assure sufficient incentives to create the desired growth of a market.

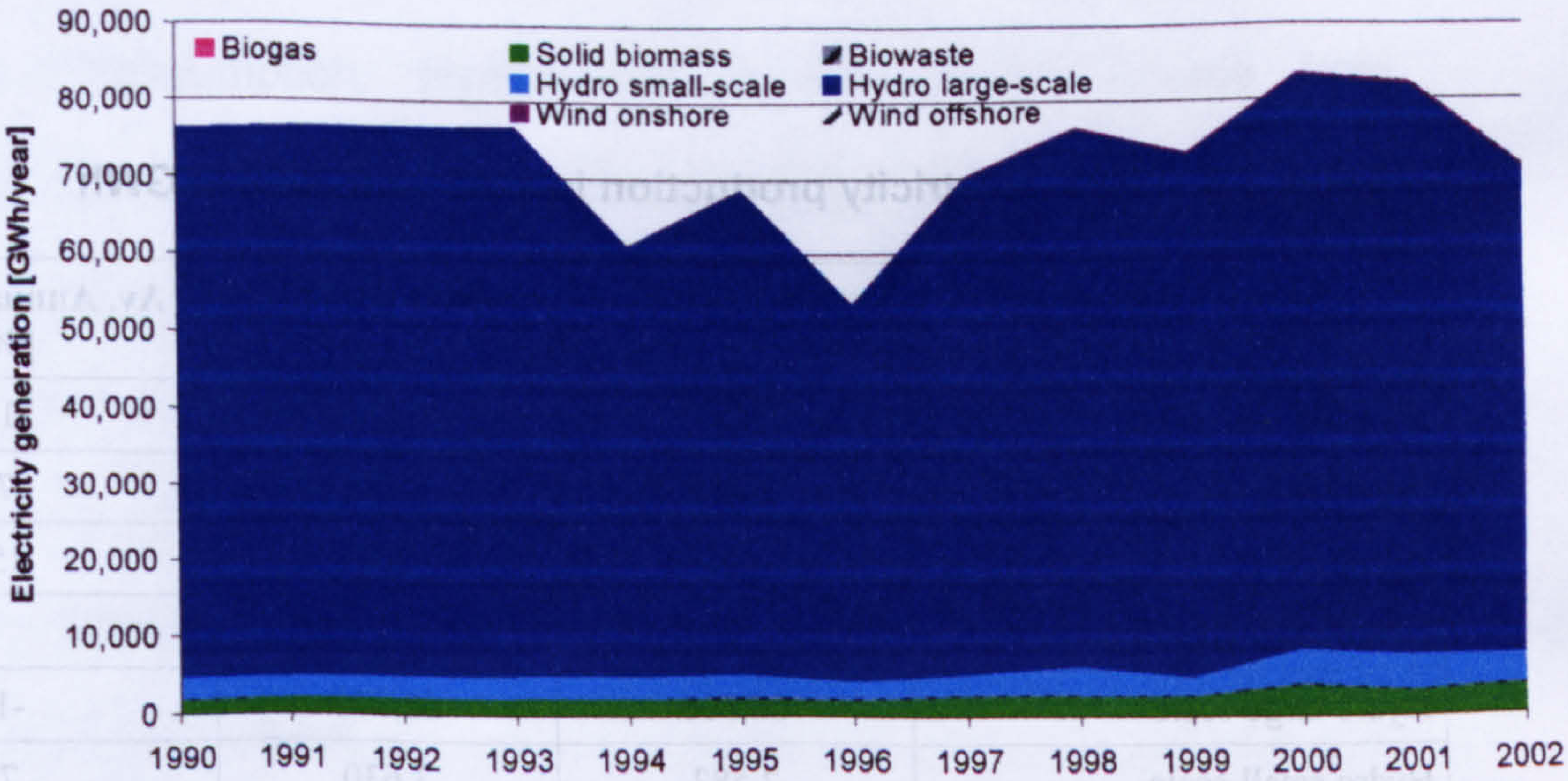
**Sweden**

Renewable electricity production has increased 7% since 1990.

The most significant technology growth has been in bio-energy which grew by 250% in since 1990 and no accounts for around 4,000,000 MWh of power. Hydropower has been and continues to be the single largest source of renewable energy in Sweden. The hydropower industry is mature and has experienced limited growth in capacity recently. In 2002 hydro generated 66,000,000 MWh. 2003 demonstrated the volatility that comes with energy sources dependent on weather (rain and snow for hydro) when total power production declined by 26%. Wind power has just recently been deployed at commercial scale in Sweden (both on-shore and off-shore) and has a reached a level of around 600,000 MWh in 2002. Deployed wind power capacity reached 399 MW by the end of 2003.

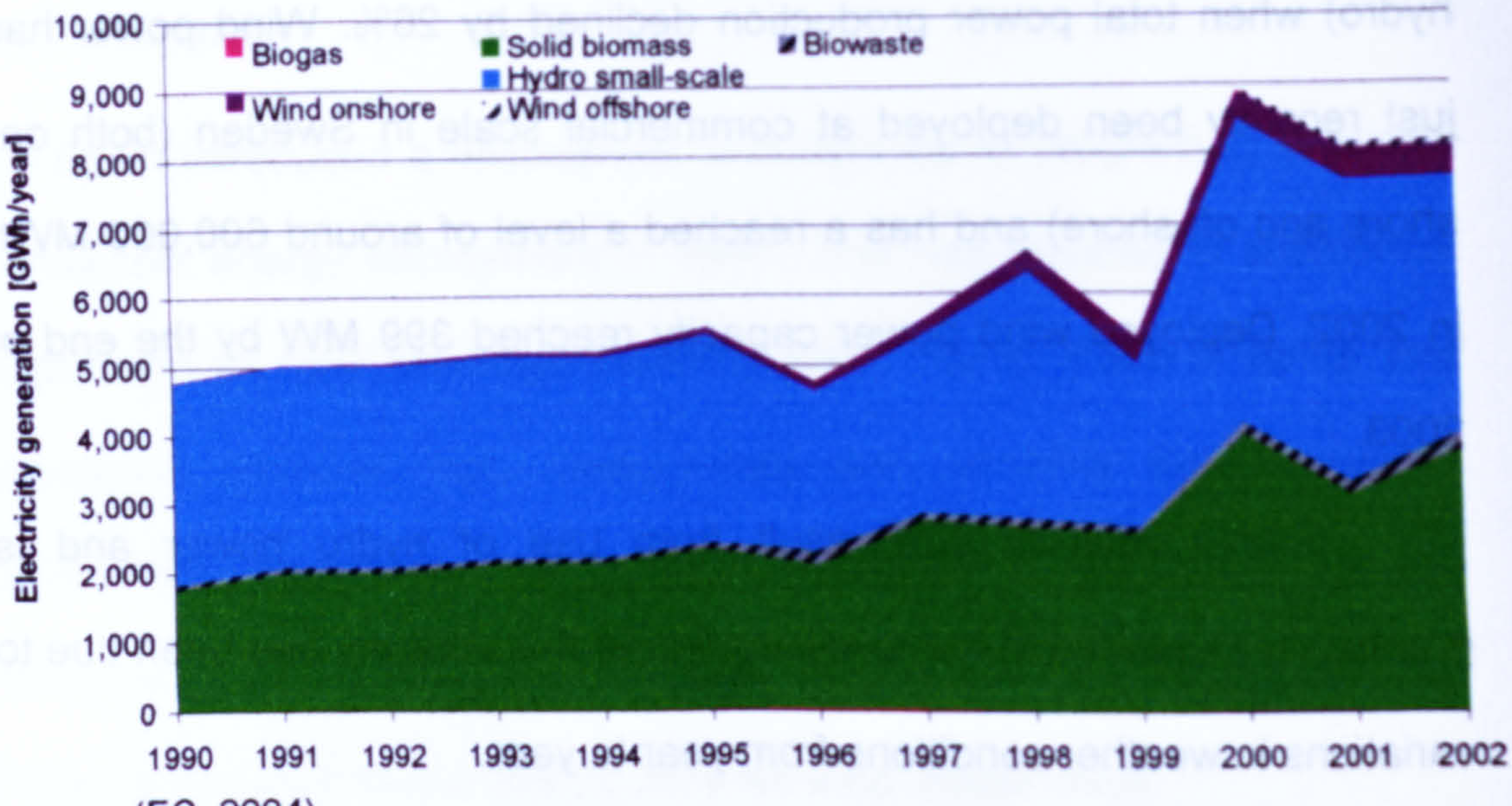
Supply volatility can result from use of hydro power and is graphically illustrated in the following figure; this volatility has been due to variations in weather conditions from year to year.

**Graph 1.4** **RES electricity production up until 2002 in Sweden**




(EC, 2004)

**Graph 1.5** **RES electricity production in Sweden up until 2002 without large hydro**




(EC, 2004)

**Table 1.8** **RES-electricity production in 1997 and 2002 in GWh**

| RES-E Technology | 1997 [GWh] | 2002 [GWh] | Av. Annual growth [%] |
|---|---|---|---|
| Biogas | 46 | 17 | -18 |
| Solid Biomass | 2,685 | 3,775 | 7 |
| Biowaste | 105 | 208 | 15 |
| Geothermal electricity | 0 | 0 | |
| Hydro large-scale | 64,560 | 62,370 | -1 |
| Hydro small-scale | 2,582 | 3,630 | 7 |
| Photovoltaics | 0 | 0 | 0 |
| Wind onshore | 205 | 600 | 24 |
| **Total** | **70,183** | **71,804** | **0.1** |
| Share of total consumption [%] | 49.10% | 46% | |
| Non-large Hydro RES-E | 5.623 | 8.230 | |

(EC, 2004)

Summary of Renewable Energy Markets and Policy

**RES targets**

The RES-E goal set for Sweden is 60% of gross electricity consumption in 2010. Sweden is different from most other countries as it has established the target as a quantity of electricity, 10,000,000 MWh. Sweden is also trying to diversify away from such dependence on hydropower by including an obligation to provide 17% of the renewable energy from non large-hydro by 2010.

**Status of the renewable energy market**

Renewables provide approximately 50% of Sweden's total electricity consumption. Hydropower is the primary source from renewables. The use of biomass has increased significantly during the past decade, but still represents a relatively small portion. Deployed wind capacity is relatively small although wind energy resources in the south of the country are comparable to Denmark's. When the new certificate scheme was drawn up by the Government, market parties expressed fear and reluctance to invest.

**Main supporting policies**

Tradable green electricity certificates (TGC) for wind, solar, biomass, geothermal and small hydro were introduced in May 2003. The system has created an obligation for end-users of power to purchase a certain amount of renewable certificates as part of their total electricity consumption (increasing to 17% in 2010). This is a similar program to that in Scotland and the UK, see chapter on Renewable Obligation Certificates (ROC).

Non-compliance leads to a penalty, set at 150% of a year's average electricity price. To secure a smooth transition, price guarantees are available for producers up to 2007. TGC system prices will be settled by supply and demand trading in a TGC market. Forecasted prices were expected in the range of 1.3 – 1.6 € cents/kWh for each certificate traded.

Wind energy investment grants to cover, or reduce, costs by 15% remain available. As a transition measure, an environmental premium for wind is available. This premium had a value of 1.9 € cents/kWh in 2003 and will decline to 0 in 2007.

**Key factors**

The TGC system is hoped to incentivise greater investment in the most cost-effective manner. Guarantees have been built into the system to insure a smooth transition to a TGC market. Also, environmental tax benefits can make some biomass CHP systems competitive. Under the TGC market system, prices may fluctuate from year to year depending on production and new deployment of renewable power plants. This holds for TGC as well as commodity prices for electricity. Both elements form a source of uncertainty for investment decisions. Sweden followed a program of promoting new renewable sources by a combination of energy taxation and environmental premium schemes until early 2003. Since May 2003, however, a major policy change has been implemented by introducing a tradable certificate scheme in order to achieve the cost-effective and market-oriented promotion of renewables. The certificate system has started-up and the effects are yet to be determined. It may result in a cost-effective development of renewables (thereby excluding some sources from the market). The Swedish government has declared that the certificate system may be opened up for imports of green certificates.

**In comparison to Scotland:**

Two important, if not critical, lessons can be seen from Sweden's experiences with renewable energy. The first lesson is the volatility of some forms of renewable energy, with the very significant decrease in production that has occurred when annual rains did not appear. Security of supply means that alternative sources must be available if the renewable energy is not forthcoming. Stand-by power sources can lead to dramatic increases in overall energy prices. The second lesson is that Sweden is also using a TGC market approach to motivate renewables expansion. It has not been in operation a sufficient length of time to be confident of its results. Scotland's program is just as uncertain of its results.

**Denmark**

Onshore wind technology has the greatest portion of renewables generation in absolute terms, as well as having the highest growth rate during the last decade. About 5,000,000 MWh of electricity was produced by on-shore wind power plants in 2002.

Economic conditions for wind energy were very stable in the 1980's and 1990's. All wind generated power was given priority access to the transmission grid for transfer to distributors and end use consumers. This priority access was complemented with a feed-in-tariff program paying approximately 8 € cents/kWh. However, the situation has changed during the last few years, primarily due to a number of changes which curtailed support for some schemes. In 2000 the annual deployment of wind power capacity peaked at just over 500 MW, followed in 2001 by only 115 MW being deployed.

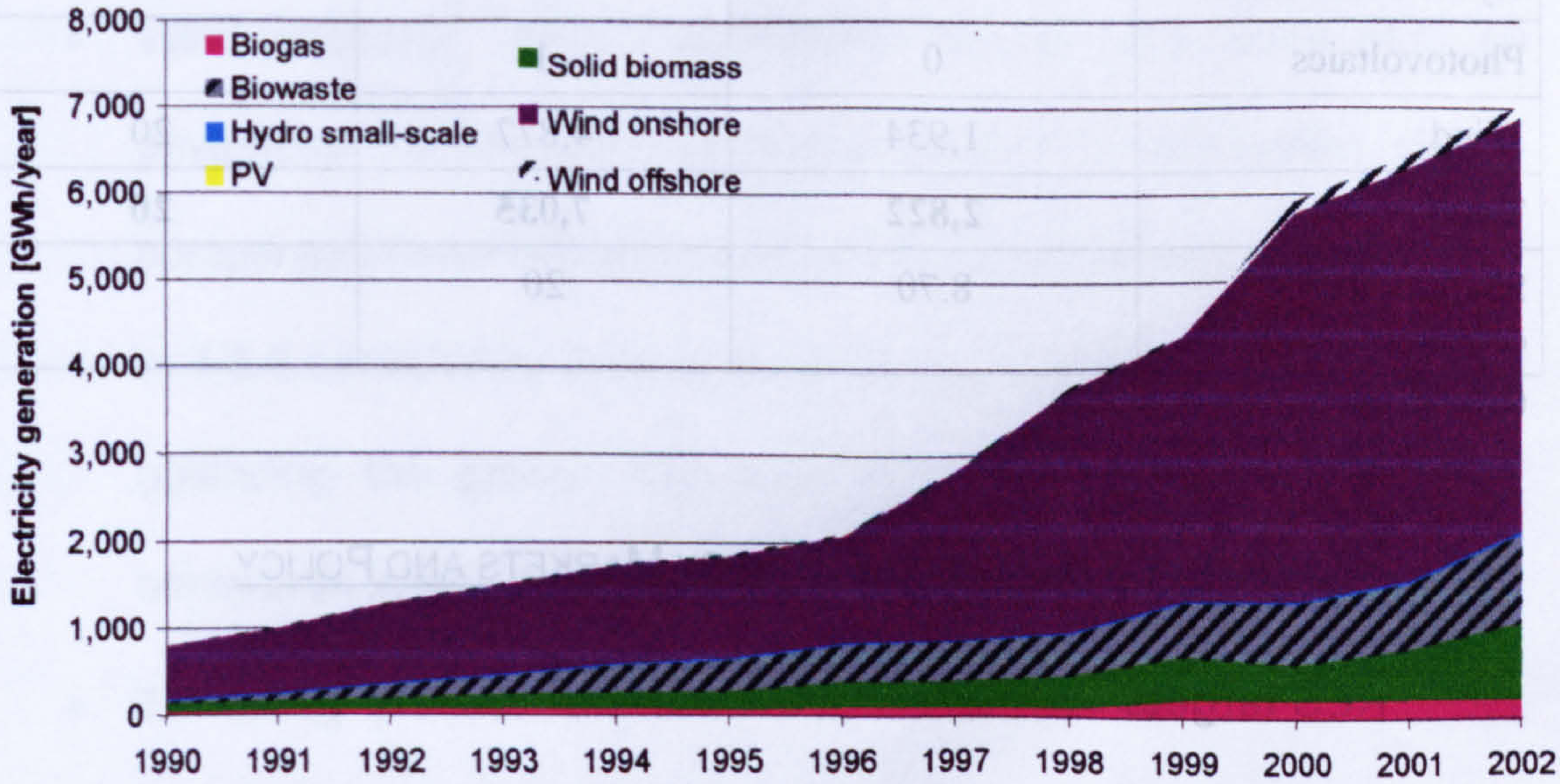
In 2002, new deployed capacity increased due to favourable re-powering conditions. Repowering is a power industry terms which consists of upgrading existing wind turbines with new technologies; it is most common is to replace the turbine blades and the generator motor.

The quantity of newly added on-shore wind capacity in 2003 declined to only about 50 MW.

Major off-shore wind energy projects were deployed in 2002 and 2003. The Horns Rev wind farm (160 MW) in 2002 and the Nysted wind farm (165.6 MW) in 2003, as well as, three smaller wind farms. This resulted in total offshore capacity of about 425 MW.

Biomass, especially biowaste, but also solid biomass and biogas, has the second largest share or renewable electricity. The detailed figures can be seen in Table 1.8, below. Little growth has occurred in the biomass sector since 2001 as earlier policies to promote biomass have been curtailed, like those for wind energy.

**<u>Graph 1.6</u>** **RES electricity production up until 2002 in Denmark**




(EC, 2004)

Due to a strong focus on environmental issues during the 1980s and 1990s, when the Danish government promoted renewable energy, it is already widely used. More than 20 % of the electricity supplied in Denmark is currently based on renewable energy and approximately 9% of the country's primary energy consumption is supplied by renewable sources. Both of these values are relatively high and significant compared to Scotland.

**Table 1.9** RES-electricity production in 1997 and 2002 in GWh and average annual growth since 1997

| RES-E Technology | 1997 [GWh] | 2002 [GWh] | Av. Annual growth [%] |
|---|---|---|---|
| Biogas | 93 | 233 | 20 |
| Solid Biomass | 314 | 875 | 23 |
| Biowaste | 461 | 1,017 | 17 |
| Geothermal electricity | 0 | 0 | |
| Hydro large-scale | 0 | 0 | |
| Hydro small-scale | 19 | 32 | 11 |
| Photovoltaics | 0 | 1 | |
| Wind | 1,934 | 4,877 | 20 |
| **Total** | 2,822 | 7,035 | 20 |
| Share of total consumption [%] | 8.70 | 20 | |

(EC, 2004)

## SUMMARY OF RENEWABLE ENERGY MARKETS AND POLICY

### RES targets

The RES-E target set to be achieved by Denmark in 2010 is 29% of gross electricity consumption.

### Status renewable energy market

The renewable energy market has dramatically declined over the last two years.

### Main supporting policies

The main promotion schemes for RES in Denmark are the following.

Act on payment for green electricity – settlement price instead of formerly high feed-in tariff.

- Wind onshore: The new tariff scheme is insufficient to attract new investments. Newly deployed turbines receive the spot price[8] plus an environmental premium[9] (maximum of 1.3 € cents/kWh) plus a compensation for offsetting costs[10] (0, 3 € cents/kWh), in total limited to 4.8 € cents/kWh. Turbine owners are responsible for selling and balancing the power. The tariff can be well below the 4.8 € cents/kWh in times of a low spot price.
- Wind offshore: New installations receive spot price plus an environmental premium (maximum of 1.3 € cents/kWh) plus a compensation for offsetting costs (0.3 € cents/kWh), in total limited to 4.8 € cents/kWh. Turbine owners are responsible for selling and balancing the power. The tariff can be well below the 4.8 € cents/kWh in times of a low spot price..
- Tendering procedure planed but conditions are currently under discussion.
- Solid Biomass: A settlement price of 4 € cents/kWh is guaranteed for a period of ten years. Additionally and as a guarantee these plants receive 1 € cent/kWh in compensation for a Renewable Energy certificate.
- Biogas: A settlement price of 4 € cents/kWh is paid

[8] Spot price – a market price paid for immediate deliver (typically less than two hours advance agreement).

[9] Environmental premium – the social value of green energy set by the Danish government.

[10] Offsetting costs – special costs associated with renewable energy production not associated with coal or gas generation.

- Waste: A settlement price of 1 € cent/kWh is paid

**Key factors**

Termination of the original high feed-in tariffs has lead to a stagnant market for additional renewable energy sources to be deployed. There has been a delay in implementing a green certificate scheme similar to the United Kingdom or other European nations. A new government was elected at the end of 2001 and initiated fundamental changes to the existing energy policies and targets. Most of the promotion schemes for renewables have been abolished. The introduction of a green certificate market has been announced but has not been implemented so far. Except for two offshore wind parks, which were already in an advanced planning phase, the strong RES development observed in the 90's has stopped.

In comparison to Scotland:

Denmark is well established with renewable energy sources being utilized in many sectors. The benefits of a long term and consistent government policy can be seen. However, the change of government in the early 2000's has lead to a total revamping of support programs and significant stagnation has occurred since that time. This is another country that has transformed its support program to a TGC market and results are as yet undetermined.

## Conclusion

This chapter has attempted to provide essential information about renewable energy as a technology, an alternative to continuing GHG pollution, and as a major government agenda to meet environmental goals and commitments.

Renewable energy resources are becoming a significant government policy issue worldwide as countries address global environmental issues. This chapter has shown the international consensus and the European consensus on reducing pollution from the production of electricity, specifically by reducing $CO_2$ emissions from power plants using fossil-fuels.

Other European countries were compared to Scotland in their pursuit of reducing GHG. All of the countries are similar to Scotland in that they have only a decade to 15 years of experience in motivating renewable energy production and technology deployment. All have met with some success and some reversals from meeting their goals. Everyone is looking for policies which will be efficient at expanding this power sector yet not create an excessive social cost.

One of the most prominent policies mechanisms being used today in Europe, and throughout many developed nations, is the tradable green certificate. This is the principle mechanism being used in the United Kingdom and Scotland since 2002.

In the following chapter an extensive description and discussion is presented of Scotland's TGC program, which is called the Renewables Obligation (Scotland).

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# Chapter 2

## *Renewables Obligation (Scotland :*

## *The New Policy Instrument and Past Policies of the 1990's*

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## Introduction

In April 2002 a new policy regime was instituted in the United Kingdom to incentivise and promoting renewable energy. In Scotland the program was called the Renewables Obligation (Scotland) (ROS), while in England and Wales the program was called the Renewables Obligation (RO). The legislation and programs in each country are identical with the exception that two markets for Renewable Obligation Certificates (ROC)[1] exist, one for Scotland and one for England and Wales.

Renewable energy is a devolved issue to the Scottish Executive, so a separate concurrent law had to be instituted in Scotland. The emphasis in this thesis is on Scottish energy and environmental issues, therefore the ROS and ROC are used in discussions; all of which applies to England and Wales and the RO. There is unified UK-wide management and operation of the two renewables programs by the Office of Gas and Electricity Markets (OFGEM), but unified UK-wide trading of electricity over the transmission grid will not occur until sometime in 2005.

The ROS is a government initiated program to create a commercial market which transacts the positive environmental and air qualities which result from electricity generated from clean renewable fuel sources.

Carbon dioxide, and other GHG, is a co-product of coal and gas fired electricity production. A significant negative externality is created when the pollution is released into the atmosphere causing local air pollution problems and

[1] Renewable Obligation Certificates (ROC) will be explained in detail later in this chapter.

adding to global climate change. However, the atmosphere is a public good, which has no specified owner who can claim property damages from the polluter, fossil fuelled power plants.

Therefore, electricity generated from fuel resources which do not pollute the environment or air have a positive utility for the public, who are ones being harmed. The government recognises this positive utility from renewable power and wishes to promote greater production of this good.

**Operation of the ROS and ROC market**[2]

The ROS requires all commercial business firms who sell electricity in Scotland to purchase ROCs equivalent to a pre-established percentage of their electricity sales, with sales measured by quantity not monetary value. These firms must comply with the ROS or faces severe penalties which range from financial penalties to the possibility of loosing their license to operate.

Once suppliers have attained the ROCs, they demonstrate compliance with the obligation by submitting the certificates to the utility regulator, Ofgem. If they do not have ROCs sufficient to match their obligation they may pay a buy-out fee to the government in replacement of each ROC not submitted. Electricity suppliers do not have to purchase the actual electricity generated from renewable power firms, they only require the ROCs. Electricity suppliers can acquire ROCs directly from renewable power producers or in the newly created marketplace for ROCs.

[2] This section is a general description of program as envisioned in the ROS legislation (ROS, 2002).

The supply of ROCs comes from renewable power producers who have received the certificates from the government. ROCs are issued to accredited power producers who use specified renewable technologies and fuel sources. One ROC is issued to renewable power producers for each MWh of electricity they produced and sold in the electricity market. This is the only point where certificates and actual physical electricity are related and interact. The price of ROCs is not directly tied in any manner to the price of electricity. Green energy producers may sell the ROCs in the marketplace to any party who desires them. These transactions can occur through bilateral negotiation, public auction[3], or other intermediaries. Any electricity suppliers, producers or brokers may participate in the trading of ROCs.

The buy-out fee paid to the government is collected and recycled to all the electricity suppliers who participated in the ROC market and submitted ROCs to meet all or just a portion of their obligation. Essentially, these firm receive a partial refund of the money spent purchasing ROCs. The amount of refund is based on the level of participation by each individual firm as a portion of the total market of submitted ROCs.

Those firms who did not participate in the ROC market and chose to pay the buy-out fee receive no refund.

To reiterate:

Renewable energy companies now produce two goods for the marketplace; electricity and ROCs. They have two revenue sources; one from the production

[3] The Non-fossil Purchasing Agency (Scotland) (NFPAS) operates a public auction of ROCS each quarter. The auction is discussed later in this chapter.

and sale of electric power, and one for the co-production and sale of ROCs. There is little or no input cost associated with ROCs production.

The electricity is sold on the open commodity market for delivery into the grid. The ROCs are sold to firms which have a demand for them. The demand has been created by the obligation to submit ROCs or an equivalent buy-out fee to the government.

The Government is using two policy variables in their management of this program; the obligation percentage which polluting firms must meet and the optional buy-out fee. The government's goal is to assure a sufficiently high ROC price that motivates rapid expansion of the renewables industry and deployment of renewable energy power stations across Scotland.

**Operation of the Renewables Obligation (Scotland)**

In this section the structure and operation the ROS as it actually took shape during its founding years of operation will be described.

**Number of Licensed Electricity Suppliers**

In Scotland there are 28 licensed suppliers, 7 of which supply to domestic customers. Scottish Power (SP) and Scottish & Southern Energy (SSE) (or their subsidiary companies) are the market dominant companies, accounting for 75% of power sales in Scotland (Energywatch, 2004 and Ofgem RO1). All of these firms were required to participate in the ROS.

At the end of an obligation period, which runs annually from 1st of April to 31st of March of each calendar year, suppliers must submit ROCs to Ofgem equal to a published schedule. See Table 2.1 below. The percentage quota schedule is established in the ROS legislation.

| |
|---|
| Example:<br>If an energy supply company sold 10,000 MWh of electricity in Scotland during the first obligation period, 1 April 2002 to 31 March 2003, the firm would be obliged to submit to Ofgem either 300 ROCs or £9,000, or a combination the two. The amount of ROCs due represents 3% of the total quantity of power sold[4]. This monetary amount represents the maximum buy-out fee payable, at £30 per ROC, if no ROCs are submitted. The buy-out fee is established in the ROS legislation. |

[4] 10,000 MWh * 3% = 300.

**Table 2.1** **Annual Obligation Quotas For The Renewables Obligation (Scotland)**

**ROS Obligation Targets**

| Obligation Period Start | End | Percentage of Total Electricity Supplied |
|---|---|---|
| 01-Apr-02 | 31-Mar-03 | 3.0% |
| 01-Apr-03 | 31-Mar-04 | 4.3% |
| 01-Apr-04 | 31-Mar-05 | 4.9% |
| 01-Apr-05 | 31-Mar-06 | 5.5% |
| 01-Apr-06 | 31-Mar-07 | 6.7% |
| 01-Apr-07 | 31-Mar-08 | 7.9% |
| 01-Apr-08 | 31-Mar-09 | 9.1% |
| 01-Apr-09 | 31-Mar-10 | 9.7% |
| 01-Apr-10 | 31-Mar-11 | 10.4% |
| *01-Apr-11 | 31-Mar-12 | 11.4% |
| *01-Apr-12 | 31-Mar-13 | 12.4% |
| *01-Apr-13 | 31-Mar-14 | 13.4% |
| *01-Apr-14 | 31-Mar-15 | 14.4% |
| *01-Apr-15 | 31-Mar-16 | 15.4% |
| Each subsequent period of 12 months ending on 31-Mar-2027 | | 15.4% |

* The original obligation quota was scheduled to increase in 2011 to a final level of 10.4%. The obligation is currently in consultation about a proposal to modify and extended the obligation to 2016 with an increase of 1% for each additional year.

(ROS, 2002 and ROS, 2004)

These 28 Scottish firms had combined electricity sales totalling 28,919,867 MWh. This translated into an obligation to submit 867,596 ROCs or equivalent buy-out funds. The United Kingdom total combined electricity sales were 279,799,067 MWh. This translated into an obligation to submit 8,393,972 ROCs or equivalent buy-out funds.

[6] The Scottish Renewables Order was the predecessor program to the ROS. The SRO program and other background issues are discussed later in this chapter.

**Certified Renewable Energy Producers**

At the start of the first obligation period 65 renewable generating stations had been accredited by Ofgem by the end of the period 31 additional stations had been accredited. The generation capacity increased from 153 MW to 258 MW, a 70% increase.

For all of the UK, 431 stations were accredited, with 505 accredited by March 2003, the end of the period. The generation capacity had increased from 1,452 MW up to 2,223 MW a 53% increase in one year.

<u>Table 2.2</u> **Number of accredited generating stations by country**

| | **England** | **Scotland** | **Wales** | **Total** |
|---|---|---|---|---|
| Biomass | 11 | 1 | 0 | 12 |
| ACT | 2 | 0 | 0 | 2 |
| Co-firing | 18 | 1 | 0 | 19 |
| Hydro <20 MW DNC | 23 | 34 | 18 | 75 |
| Landfill gas | 210 | 9 | 7 | 226 |
| Micro hydro | 3 | 25 | 1 | 29 |
| Off-shore wind | 2 | 0 | 0 | 2 |
| On-shore wind | 42 | 26 | 23 | 91 |
| Sewage gas | 49 | 0 | 0 | 49 |
| **Total** | **360** | **96** | **49** | **505** |

(Ofgem RO1, 2004)

Table 2.3 Number of ROCs issued in 1st obligation period, by country

| | England | Scotland | Wales | Total |
|---|---|---|---|---|
| Biomass | 574,828 | 33,266 | 0 | 608,094 |
| ACT | 173 | 0 | 0 | 173 |
| Co-firing | 385,106 | 44,753 | 0 | 429,859 |
| Hydro 20 MW DNC or less | 20,725 | 365,383 | 112,464 | 498,572 |
| Landfill gas | 2,575,315 | 96,533 | 44,896 | 2,716,744 |
| Micro Hydro | 772 | 39,769 | 379 | 40,920 |
| Off-shore wind | 2,347 | 0 | 0 | 2,347 |
| On-shore wind | 305,890 | 430,441 | 351,326 | 1,087,657 |
| Sewage gas | 178,303 | 0 | 0 | 178,303 |
| **Total** | **4,043,459** | **1,010,145** | **509,065** | **5,562,669** |

(Ofgem RO1, 2004)

Certified power producers in Scotland generated 1,010,145 MWh of electricity during the first obligation period, thereby earning the same quantity of ROCs. In England and Wales certified producers generated 4,552,524 MWh of green energy and received the same number of ROCs.

Supply and demand of ROCs in Scotland:

Supply = **1,010,145** Demand = **867,596**

Supply and demand for ROCs in the UK:

Supply = **4,552,524** Demand = **8,393,972**

Recall that ROCs can be used in meet obligations in either Scotland or England and Wales. Therefore, there is an excess supply of certificates produced in Scotland, while there is a very significant shortage of ROCs to meet demand in the UK as a whole.

The only option available to the electric supply firms who do not have sufficient ROCs is to pay the buy-out fee. A shortage of 3,841,448 ROCs is equivalent to **£115,243,440**.

**Eligible Types of Technology**

Not all forms of renewable energy are eligible for the ROS program. Eligibility is dependent on the type of technology and the scale of production. Which clean energy technologies were to be included or and excluded was a source of public debate and widely consulted. Generally, two criteria were used to decide the matter. The first criteria concerned the technology involved; did it need additional financial support for it to be commercial viable in the near term. The second criteria examined the social desirability of the technology. Examples of social criteria are; large hydro which was deemed ineligible by the first criteria and waste-to-energy which was deemed ineligible by the second (EUFORE, 2001).

Yet there are inconsistencies with these criteria. Co-firing of biomass with coal is allowed in for a limited time frame and limited quantity of ROCs.

Table 2.4 ROS Eligible Technologies

| | |
|---|---|
| Wind | Offshore or Onshore |
| Marine | Wave, Tidal, Current |
| Solar | Photovoltaic |
| Hydro | Small-scale hydro generating station (declared net capacity between 1.25 MW and 20 MW)<br>* Micro-scale hydro generating station (declared net capacity less than 1.25 MW) |
| Biomass | * Biofuel produced from pyrolysis of biomass.<br>* Biogas produced from anaerobic digestion, gasification or pyrolysis of biomass.<br>* Generation station is fuelled by biomass combustion. |
| Co-fired Biomass | * Generation station is fuelled part by biomass and part by fossil fuel. Only that portion of energy derived from biomass is eligible, after 1 April 06 biomass portion declines to 75% eligible, after 1 April 2001 co-firing is not eligible. |
| Waste | * Biofuel from pyrolysis of waste.<br>* Biogas produced from anaerobic digestion, gasification or pyrolysis of waste.<br>* Sewage gas and Landfill gas. |

(ROS, 2002)

Debate continues over which technologies to include and support (Ofgem A, 2001). The length of time co-firing biomass with coal in the Longannet Power Station was extended after political debate in 2004. The reason for the extension is to assist growers of energy crops with an assured market (RPA, 2003). This action will likely extend the commercial life of Longannet and other coal-fired plants. However, the use of escaping methane from old coal mines was rejected. Supporting methane capture technology would have assisted the diversion of a powerful GHG, $CH_4$ to a beneficial use, electricity production (WEC, 2005).

**Buyout Fee and Recycling of Funds** (figures from Ofgem RO1, 2004)

The option exists for suppliers to pay a buy-out fee to discharge their obligation. The option maybe exercised for any, or all, of the obligation. For the first obligation period, the buy-out price was set at £30 per ROC. The buy-out fee is adjusted once a year at the beginning of new obligation cycle. Ofgem matches the fee increase to the change in the Retail Price Index for the past year. The second and third years of the ROS had buy-out fees set at £30.51 and £31.39, respectfully (Ofgem RO2, 2005).

The inclusion of the buy-out fee alternative in the ROS program was motivated by several reasons. First, the transaction costs of participating in the ROC market could be prohibitive for some companies, while a simple cash fee paid directly to Ofgem would fulfil the obligation more efficiently, i.e. small energy producing firms which would owe only a small number of ROCs to Ofgem. Ten of 28 energy producers in Scotland were obligated to submit less than 1,000 ROCs to Ofgem the first year of the ROS's operation.

Another reason for the buy-out option was the total obligation due for the entire United Kingdom was expected to be greater than the forecasted amount of ROCs that would be produced and available each period. A mechanism was needed to compensate for the short fall of ROCs.

The "excess demand" is actually a deliberate policy objective of the government. It is instituted to assure demand will exceed supply, so all ROCs produced will have demand for them in the marketplace. This will also assist in sustaining high market prices for ROCs, as suppliers bid against each other for the limited number of ROCs.

A final reason for the buy-out fee was to increase the opportunity for optimal decision making by individual firms. Each firm could decide for themselves which method, or combination of methods, was the most efficient way to meet their regulatory obligation.

**Recycling of Funds**

Buy-out fees paid to Ofgem are collected than distributed back to the energy suppliers who participated in the ROC program. The funds are recycled on a proportional basis, based on the total number of ROCs submitted against the amount submitted by each supplier.

| Example: |
| --- |
| If an energy supply company submitted 300 ROCs to meet their renewables obligation, they would be eligible to receive back a portion of the total buy-out fees collected by Ofgem. If the 300 ROCs represented 10% of the total ROCs submitted to Ofgem for that obligation period, the firm would be entitled to 10% of the fund created by the collect fees. Assuming the buy-out fund is worth £50,000, the firm would receive recycled funds of £5,000 from Ofgem.<br>If the firm had chosen to pay the buy-out fee and not submit ROCs, the firm would not receive any of the funds. If the firm had chosen to combine the two methods, it would receive funds back from Ofgem in proportion to the ROCs it contributed. The buy-out fee paid in by the firm is irrelevant to the refund amount. |

## A Simplified Case Study

This section now presents a case study from ROS's first year of operation and Scottish and Southern Energy (SSE).

In the first obligation period a total of 867,596 ROCs were required from the 28 electricity suppliers in Scotland; 3% of the 28,919,867 MWh of electricity sold in Scotland that period.

SSE submitted 115,755 ROCs, but had an obligation of 223,344 certificates. All ROCs submitted by SSE, were collected from renewable power station which they owned. SSE did not purchase any ROC in the open market.

The portion of SSE's obligation not met through submitting ROCs was fulfilled through payment of a buy-out fee, approximately £3.2 million.

SSE's ROCs accounted for 26% of the total ROCs submitted in Scotland, so SEE was entitled to a refund equal to 26% of the total buy-out fees collected for that period.

Ofgem recycled funds totalling £2.8 million to SSE.

After accounting for the refund, SSE met their obligation by submitting 115,755 ROCs and £400,000.

The same buy-out recycling mechanism resulted in a refund of £3.8 million to Scottish Power (SP) for the same period. The below table itemises the funds returned to participants of the ROC program in the first year in Scotland.

**Table 2.5 Redistribution of ROS buy-out**

| Supplier licence | Buy-out redistributed for ROCs/SROCs produced (£) |
|---|---|
| Atlantic Electric and Gas Ltd | 0 |
| British Energy Generation Ltd | 362,351 |
| British Gas Trading Limited | 2,063,851 |
| Cinergy Global Trading Ltd | 3,674 |
| Economy Power Ltd | 74,288 |
| Electricity Direct (UK) Ltd | 418,079 |
| Fortum Direct | 0 |
| Fortum Energy Plus Limited | 0 |
| London Electricity plc | 186,451 |
| Maverick Energy Ltd | 0 |
| Norweb Energi Ltd | 0 |
| Npower Direct Ltd | 30,125 |
| Npower Ltd | 672,789 |
| Npower Northern Ltd | 92,872 |
| Npower Yorkshire Ltd | 95,439 |
| Opus Energy Ltd | 235 |
| Powergen (UK) plc | 241,402 |
| Powergen Retail Ltd | 470,133 |
| ScottishPower Energy Retail Ltd | 3,778,730 |
| Seeboard Energy Ltd | 36,461 |
| Severn Trent Energy Ltd | 47 |
| SSE Energy Supply Ltd | 2,726,466 |
| TotalFinaElf Gas & Power Ltd | 0 |
| TXU Direct Sales Ltd | 0 |
| TXU Europe (Ah Online) Ltd | 8,550 |
| TXU Europe (AHGD) Ltd | 5,181 |
| TXU UK Ltd | 0 |
| UK Electric Power Ltd | 0 |
| **Total** | **11,267,124** |

(Ofgem RO1, 2004)

**Effect of the Recycled Buy-out fee**

A major result of the buy-out fee being distributed back to participants is the market value for ROCs is not directly constrained by the value of the buy-out fee. The market price for ROCs is determined by the buy-out fee plus the expected refund.

If Scottish & Southern Energy had not participated in the ROC program and they would have had to pay an additional £3,500,000 as the buy-out fee to meet their obligation, Their total cost to meet the obligation would have added up £6,700,000. (SSE did have 116, 000 ROCs, this is a hypothetical, "if they did not have ROCs"; SSE would have had to pay £3,500,000 in additional fees)

This means the 115,755 ROCs which were submitted by SSE off-set £6,300,000 in buy-out fees or approximately £55 per ROC. The £6,300,000 amount is the net amount not paid in to the fund (£6,700,000 - £400,000, after the recycled funds are accounted for). So the full value of a ROC to SSE is £55, not the £30 per ROC buy-out fee.

For SSE, SP and other energy companies that produce the necessary ROCS through internal operations, i.e. ownership of renewable power stations, ROCs could represent up to 75% of the revenue earned by generating and selling certified renewable energy. The wholesale electricity market in Scotland traded between £16 and £22 per MWh during 2002/03 period, depending on seasonal and daily demand for power. ROCs were earning SSE £55 per MWh.

**Example 2.1** **Actual Ex-post Value of ROCs to Scottish & Southern Energy**
(2002/2003 obligation period)

ROC Obligation 223,344

Participation in Program
Fulfilled by *self-generated* ROCs and cash

| | |
|---|---|
| 115,755 | ROCs |
| £3,227,670 | Cash Buy-out |
| £2,726,466 | Refund |
| £ 501,204 | Net Cash out |

Non-participation in Program
Fulfilled by
£6,700,320 Cash Buy-out

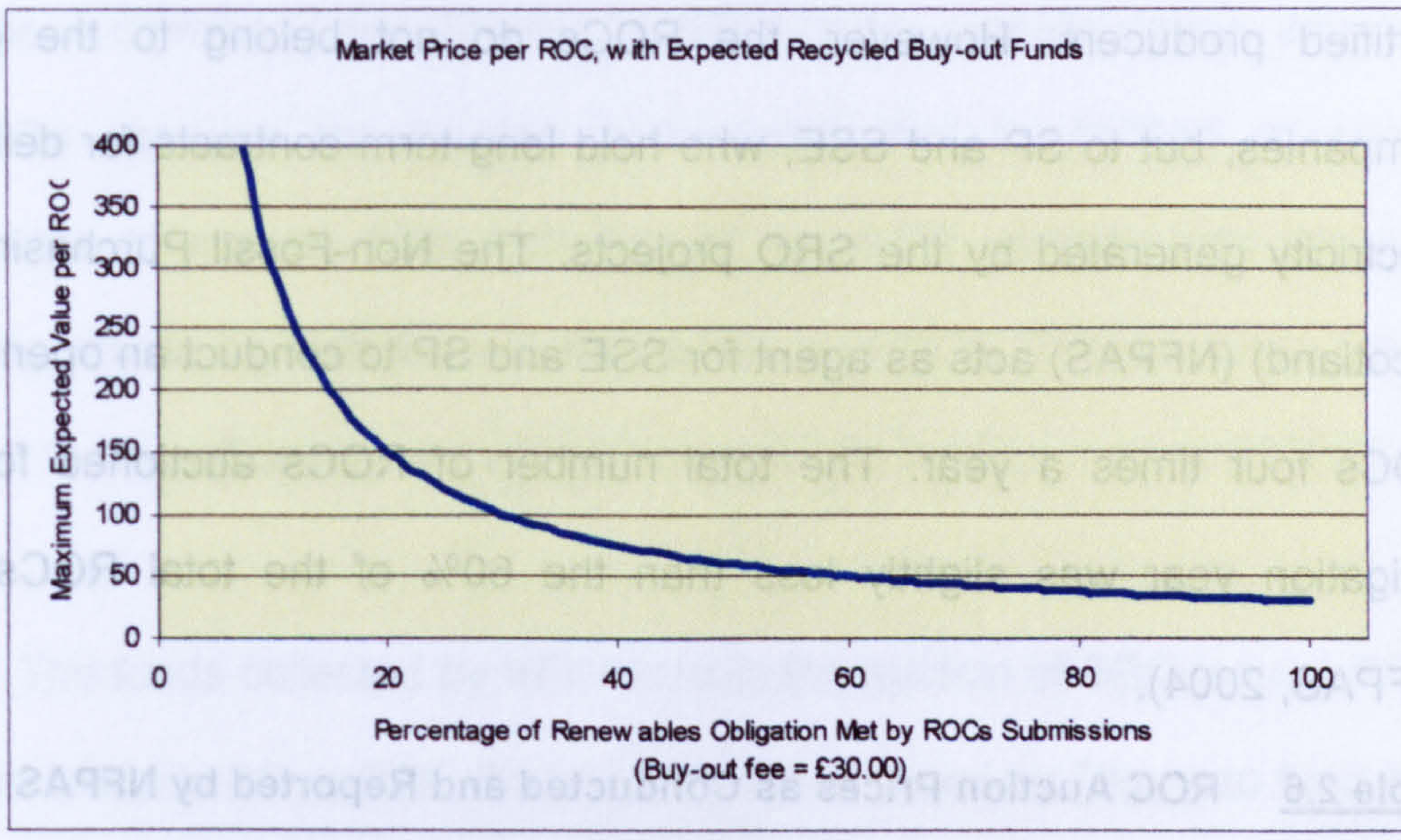
Offset: £6,700,320 - £501,204 = £6,199,116, value of ROCs not submitted.

£6,199,116/ 115,755 ROCs = **£53.55/ROC, true ex-post value of submitted ROCs**

(Note: All amounts are related to transactions under ROS and do not include activities in England and Wales, where SP and SSE were also major participants. Difference between actual amounts and rounded amounts in above discussion are due to the buy-out fund being under paid, as several companies had gone into receivership)

A power supply firm which purchased all of the necessary ROCs from the marketplace at £47(see Graph 2.1), in the first obligation period would have had an ex-post value after the buy-out fee refund of £23. £7 less than the buy-out fee during that period. Participation in the ROCs market and using ROCs to meet the obligation has a cost of £23 per certificate. Meeting the obligation by simply paying the buy-out fee has a cost of £30 per certificate.

**Graph 2.1** **Market Prices per ROC, with Expected Recycled Buy-out Funds**




Note: Assuming no transaction costs, the expected market value of ROCs with the buy-out funds being recycled is: ***Market Price/ROC = Buy-out Fee/ROC + Recycled Funds/ROC***, where the *Buy-out fee = £30/ROC* and *Recycled Funds = [(Total ROCs Obligated – ROCs submitted)*£30]*. Using the above graph, the estimated maximum market value of ROCs in the first period should have been £54.55, with 55% of the obligation being met with ROCs.

### Market for ROCs

The trading of ROCs between renewables producers and electricity suppliers happens in two distinct manners. The first is a standard commercial trading market; parties seek each other out and negotiate bilateral contracts for the ROCs (contracts do not have to include the physical electricity being generated). Any legal contract may be negotiated. These deals are typically confidential and details such as price, quantity, contract duration and delivery terms are not available to other participants in the market.

The second manner in which ROCs are transacted is an open public auction. Most of the renewable energy projects constructed under the Scottish

Renewables Order[6] (SRO) contracts in the 1990's were eligible to become ROC certified producers. However, the ROCs do not belong to the generating companies, but to SP and SSE, who hold long-term contracts for delivery of all electricity generated by the SRO projects. The Non-Fossil Purchasing Agency (Scotland) (NFPAS) acts as agent for SSE and SP to conduct an open auction of ROCs four times a year. The total number of ROCs auctioned for the first obligation year was slightly less than the 60% of the total ROCs available (NFPAS, 2004).

**Table 2.6** ROC Auction Prices as Conducted and Reported by NFPAS

| Date (month & year) | | Amount (£) | Quantity (approx.) |
|---|---|---|---|
| October | 2002 | £47.13 | 85,000 |
| January | 2003 | £47.46 | 64,000 |
| April | 2003 | £46.47 | 190,000 |
| July | 2003 | £48.21 | 158,000 |
| October | 2003 | £45.93 | 123,000 |
| January | 2004 | £47.46 | 96,000 |
| April | 2004 | £49.11 | 166,000 |
| July | 2004 | £52.07 | 176,000 |
| November | 2004 | £48.50 | 129,000 |
| January | 2005 | £47.46 | 151,000 |

(NFPAS, 2004 and 2005)

The public auctions fulfil an important role beyond market making and the exchange of ROCs. It provides a public and transparent price signal which all interested parties can use for contract negotiations. Market agents can use this information to develop better negotiating strategies and operate with improved information and expectations. Greater confidence in optimal decision making can be gained for each firm's specific trading circumstances.

The portion of ROCs being auctioned has declined as more non-SRO projects have been commissioned. Starting in 2005, under new legislation, any producer of ROCs can use the auction system operated by NFPAS to send their certificates to market. This inclusion of non-SRO projects was the result of lobbying efforts by both buyers and sellers of ROCs. They mutually expressed support for the efficiency and effectiveness of the auction market (NFPAS, 2004).

**Taxes**

The funds collected by NFPAS from the auction of SRO issued ROCs are not forwarded to SP or SSE. Rather, they are retained by Ofgem to fund the price subsidy needed for SRO contracts. The collection of SRO ROC moneys has lead to the suspension of the Fossil Fuel Levy in Scotland. Approximately £23.7 million in taxes were avoided by Scottish electricity consumers starting the first year the ROS was implemented. Until November 2004, the total FFL avoided taxes have added up to approximately £57 million (NFPAS, 2004).

Most electricity generated by SRO and ROS eligible power producers is exempt from the Climate Change Levy (CCL). The CCL was created in 2001 and is applied to all industrial and commercial consumption of electricity that comes from fossil-fuel or nuclear power sources. Household consumption is not taxed. The levy is charged at a flat rate on each kWh of energy consumed, at the following rates:

- Electricity 0.43p/kWh
- Natural Gas 0.15p/kWh
- Coal/Lignite 1.17p/kg (approximately 0.15p/kWh)
- LPG 0.96p/kg (approximately 0.07p/kWh)

(CCL, 2004)

Other non-SRO and non-ROS produced renewable power can also be exempted from this tax. The CCL does not directly deal with or affect the ROC market, but it does have an impact on the demand for the physical commodity produced. Renewables generated electricity purchased for use by a commercial or industrial consumer is exempted from paying the CCL. This exemption can represent a savings of 5% - 15% of the total cost of electricity. For large electricity intensive industrial processes this CCL exemption can represent a significant change in their costs of production. The CCL is essentially a penalty on fossil-fuelled and nuclear energy and a subsidy of renewable power.

**Near Term Course for the ROS**

The Renewables Obligation Scotland has completed two and-a-half years of operation. During autumn 2004, the Scottish Executive scheduled a consultation to advice on additional or corrective legislation to the ROS (SE-ROS 2005). The proposed changes as proposed from the consultation are:

1) Increase the obligation time frame and amount. Currently the obligation is scheduled to increase until 2011 and have an obligation of 11.4%. The proposal is to extend the schedule to 2016 and increase the obligation by 1% each year, so the final year has a maximum obligation of 15.4%. This final level will be in effect until 2027.

Reasoning: renewable energy projects are dependent on long-term capital financing. Financing terms for commercial energy projects normally require projects to have high confidence in their revenue stream for at least 15 years, the standard length of capital loans in the industry (Casazza, 2003). To provide this confidence, the obligation must always have a time frame longer than the loan terms and the expected market price for ROCs needs continued support by the obligation being higher than the available number of ROCs.

2) Extension of ROS to allow participation of Northern Ireland. It is expected that Northern Ireland will institute similar legislation to the ROS in 2005. The program will be called Northern Ireland Renewables Obligation (NIRO). The proposal is to have the same unified market for ROCs as exists with England, Wales and Scotland.

Reasoning: the larger the market the greater opportunity to increase efficiency and effectiveness of the program by allowing more competition between sellers and buyers of ROCs. It will allow for greater optimization of geographic renewable energy resources that can benefit the entire United Kingdom.

3) Introduction of late-payment surcharges buy-out fees and the mutualisation of the ROS buy-out funds.

Reasoning: the buy-out fees equalling £23.7 million were either paid late or were completely defaulted upon between the RO and the ROS. Less than £500,000 of the shortfall was in the ROS fund. Over £16 million of the shortfall in the RO fund was due to a single supplier going into default, TXU UK Ltd. Actual recycled funds were £2.80/ROC less than the expected expost market value with refund, because of the £23.2 million shortfall in the England and Wales buy-out fund. This had a chilling effect on the market for ROCs as well as damaging investor confidence in the renewables energy industry.

4) Introduction of a unified buy-out fund and recycling for the ROS, RO and NIRO.

Reasoning: the same as stated in item 3 above, there is opportunity for arbitrage between the RO and ROS funds, and NIRO funds when it is created. By handling the funds in a UK wide manner the arbitrage potential is eliminated.

5) Allow small generator (less than 50 kW capacity) to accumulate and submit ROCs on a flexible schedule.

Reason: to allow small operators to minimize their transaction costs and motivate greater uptake of renewables by households and community based systems.

6) Allow biomass generators to supplement their energy crop fuel with municipal waste or fossil fuel (methane or coal) up to 10% of the total energy input to the station.

Reasoning: technical efficiency of biomass combustion, some generating systems may occasionally need high grade carbon fuels to be included. This is especially the case of coal-fired plants which have been converted to use biomass fuels.

**Potential for Strategic Behaviour**

The ROCs market has been consciously designed by government regulators to allow as much private initiative and open market incentives as possible. But this design has left room for strategic behavior by both sellers and buyers that may distort the market equilibrium and even destabilize confidence in the market and thus slow the expansion of renewable energy.

The obligation quota can act as a ceiling on the amount of renewables that will be built. As a greater percentage of the renewables obligation quota is met the value of ROCs decrease until the value collapses to zero (See Graph 2.1). It is highly unlikely that a firm would enter the market and produce ROCs that would exceed the quota. In fact, there is motivation and potential for firms to behave strategically, alone or in collusion with others, by under producing energy and causing the price of ROCs to remain higher than they would have otherwise. Market concentration and production management should be monitored accordingly.

Licensed electricity supply companies who have their own renewable generation facilities have a distinct revenue advantage. They are able to capture the total ex-post value of the ROCs. The auction price of ROCs has consistently been £5 to £9 below the theoretically maximum ex-post price. Various types of transaction costs and market risks can account for this value gap. The smaller a firm is the higher their time discount rate is likely to be, therefore buyers of ROCs can negotiate lower prices because buyers only need ROCs annually, after the end of the obligation period. Transaction costs contribute to the value gap. As discussed earlier there is risk in the buy-out fund being fully funded and recycled. Finally, there is the stochastic nature of ROC production, if the natural resources, e.g., sun, rain and wind, are better than forecast, ROC prices will be depressed.

Technologic obsolescence is a greater risk in the renewables power generation sector than the rest of the energy/power industry. The learning curves for most renewables technologies are steep and costs are falling quickly. The physical number of manufactured units is growing so rapidly, that cost curves for wind energy have been reduced by 50% in ten years (Wene, 2003). The potential for new entrants into the marketplace and decreasing ROC prices because of lower average costs may bring over production and collapse of prices, or at least lower prices, as discussed previously. Also, negotiating strength shifts to buyers and away from sellers, as sellers need long term contracts to guard against this risk. Rent seeking by purchasers is likely.

Renewables technology is capital intensive and requires large amounts of long-term capital financing. Established firms like SP and SSE, and other major power producers, have a significant competitive advantage over smaller or newer firms in the market because of their pre-existing dominance, size, and ability to distribute investment risk over all corporate assets, not just against a single project. The large firms are possibly better equipped to build large wind farms and gain economic rents from economies of scale.

**Renewables Policy during the 1990's**

Prior to 2002, the principle program for renewables development in Scotland originated in 1994 and was a series of three orders called the Scottish Renewables Obligation (SRO). These orders placed an obligation on the two electric utility monopolies (Scottish & Southern Energy and Scottish Power) which operated in Scotland. They were required to purchase all renewable energy generated by contracted projects. The Scottish government set specific goals with each new order for the types of renewables technology to be contracted, e.g. small and large wind farms, biomass gasification, municipal waste combustion, landfill gas, and small hydro. The MW capacity to be built for each technology band was also pre-determined before each new order. Each technology was also to receive different support levels in the form of capital construction grants and price subsidies for the electricity sold. (Scottish Parliament, 2000)

The Fossil Fuel Levy (FFL), a new tax on electricity produced using fossil fuels, was created in conjunction with the SRO. The funds collected from the FFL were used to compensate the utilities for higher prices that were necessary to pay for electricity delivered from renewable power generation companies. This tax was as high as 11% in the mid-1990's (Scottish Parliament, 2000).

Possibly the most important aspect of the SRO/FFL legislation was not its effect on renewables but that nuclear energy was exempt from the levy. The fiscal impact on the nuclear energy industry was magnitudes greater than that on renewables. In the ten years that the FFL operated in Scotland, 25% to 35% of electricity produced was by nuclear plants. The levy exemption amounted to a several hundred million pounds profit support for the industry that had higher production costs that its closest competitors, coal-fired and natural gas-fired power producers. This created a significant distortion of the market and acted as a major subsidy to nuclear energy which the government was trying to privatise (Mitchell and Conner, 2004).

The sum total of renewable energy projects actually constructed under the SRO policy regime is listed below. The final SRO order was in 1999, but less than half of the contracted projects from 1994 to1999 have been built as of December 2004. Price supports will continue as late as 2015.

**Table 2.7 Scottish Renewables Obligation Projects**
(commissioned as of 12/2004)

| Technology | Projects | MW |
|---|---|---|
| Onshore Wind Farms | 17 | 79 |
| Shoreline Wave | 1 | 0.05 |
| Hydro | 1 | 3.3 |
| Biomass Combustion | 1 | 12.5 |
| Landfill Gas | 9 | 20.7 |
| **TOTAL** | **29** | **116.0** |

(SE-RED, 2004)

Most of the electric energy produced in the "Other renewables" category during 2002 was derived from SRO supported projects.

**Renewables Policy since 2002**

With the election of Labour in 1997, with its manifesto including the expansion of renewable energy sources, extensive public consultation took place about energy policy (Kimber, 2005). One result of these consultations was a new renewable energy support program which was launched in April 2002. It is called the Renewables Obligation (Scotland) (ROS). It is important to distinguish between the name of this current program ROS and the prior program SRO.

The affect of this new support program on the rate of construction and commissioning of new renewable energy projects has been dramatic. Since inception there has been a 160% expansion in generating capacity in just 33 months. Only two small demonstration projects are being directly funded by government support. One of these projects is a proto-type marine generation system and the other a small municipal waste-gas system. The ROS program has been extensively discussed earlier in this chapter.

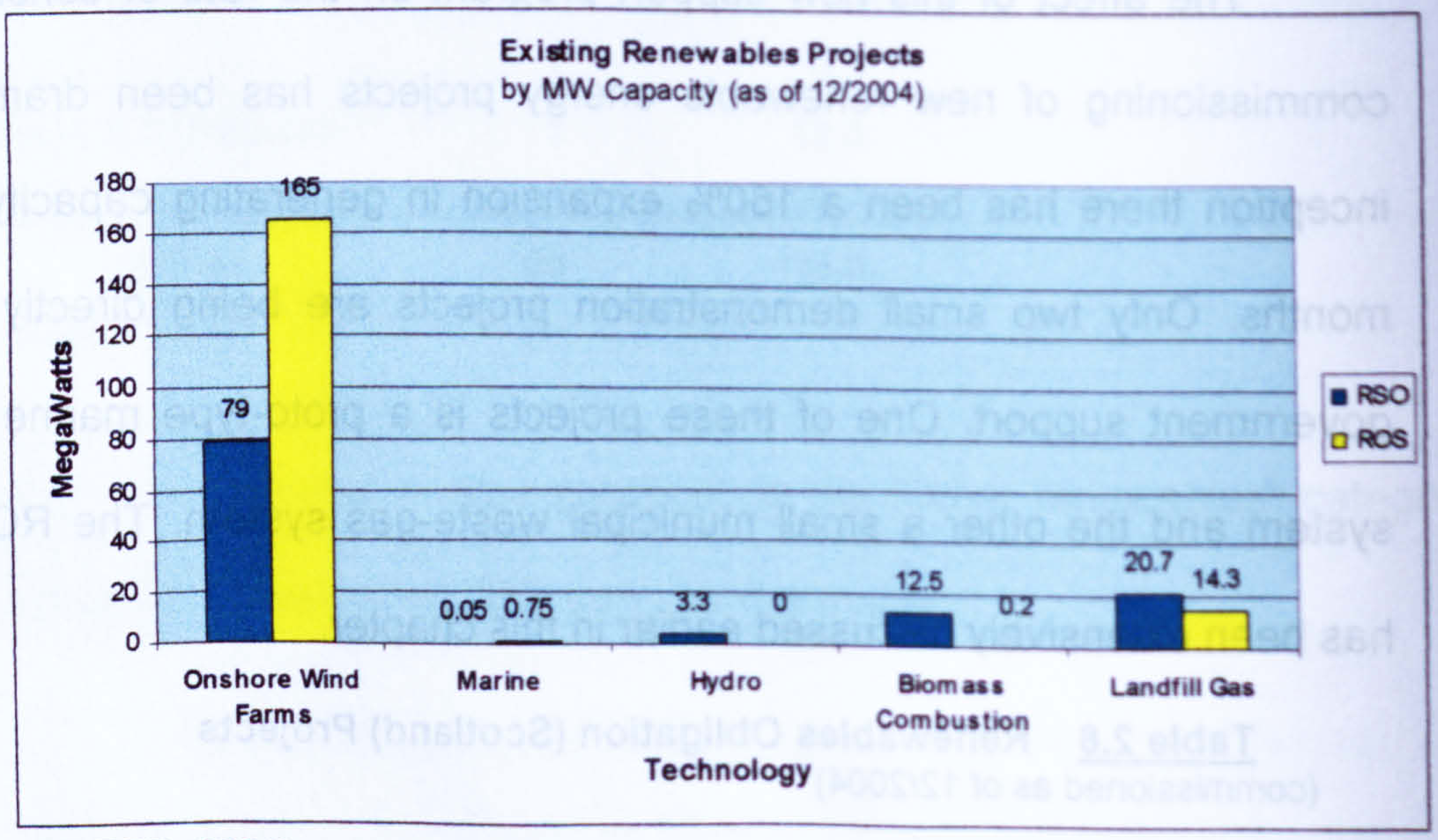
Table 2.8 **Renewables Obligation (Scotland) Projects**
(commissioned as of 12/2004)

| Technology | Projects | MW |
|---|---|---|
| Onshore Wind Farms | 5 | 165 |
| Wave-offshore | 1 | 0.75 |
| Hydro | 0 | 0 |
| Biomass Combustion | 1 | 0.2 |
| Landfill Gas | 8 | 14.3 |
| **TOTAL** | **15** | **180.25** |

* in addition to these projects, Longannet and Cockenzie coal-fired power plants have become certified to generate power using a portion of combustible biomass that qualifies as renewable energy. (SE-RED, 2004)

While government support has continued, it has been significantly redirected to support technology in the research and development stage. This basic research level technology is distant from commercial viability and therefore needs support as only limited private funds are being invested. Funds have been diverted to assist Scottish communities develop indigenous energy supply projects (SCHRI, 2004).

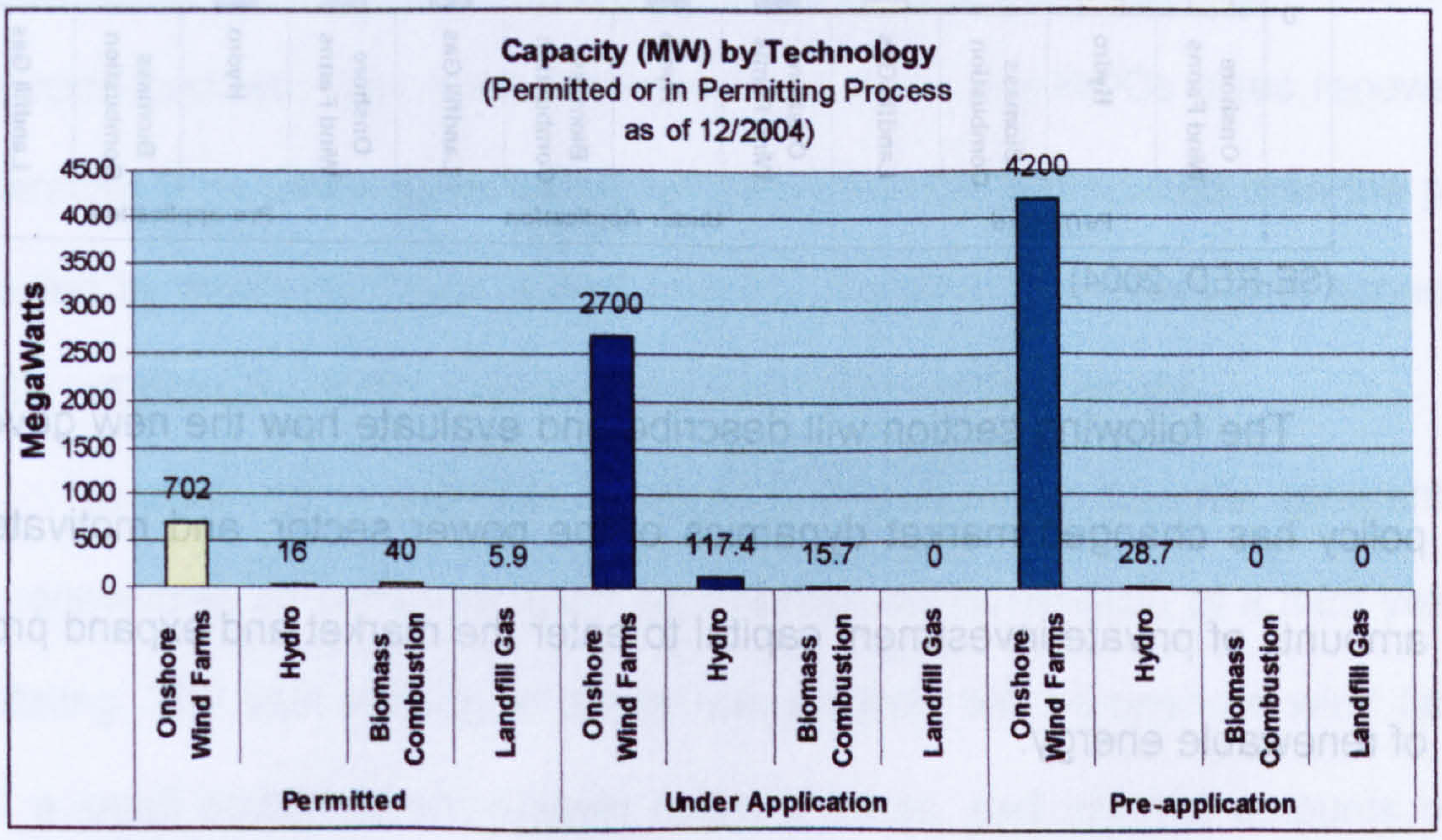
**Chart 2.1** **Existing Renewables Projects in Scotland**
(commissioned as of 12/2004)




(SE-RED, 2004)

More dramatic growth is expected to occur in the near term. The quantity of renewable energy projects currently consented for construction will bring a 250% expansion over the 180 MW of existing capacity, as they are commissioned. Projects that have applied for government consent to build and are currently being evaluated by the Scottish Executive, local planning boards or councils, may account for a 1000% increase in renewables capacity. Project developers have notified local councils and the Scottish Executive of an additional 4230 MW of capacity that is being contemplated; technical and environmental feasibility studies are being conducted at this time. These pre-application (study and scoping stage) projects would represent a 23-fold increase in capacity over existing renewable energy projects. These pre-application projects are almost exclusively onshore wind farms.

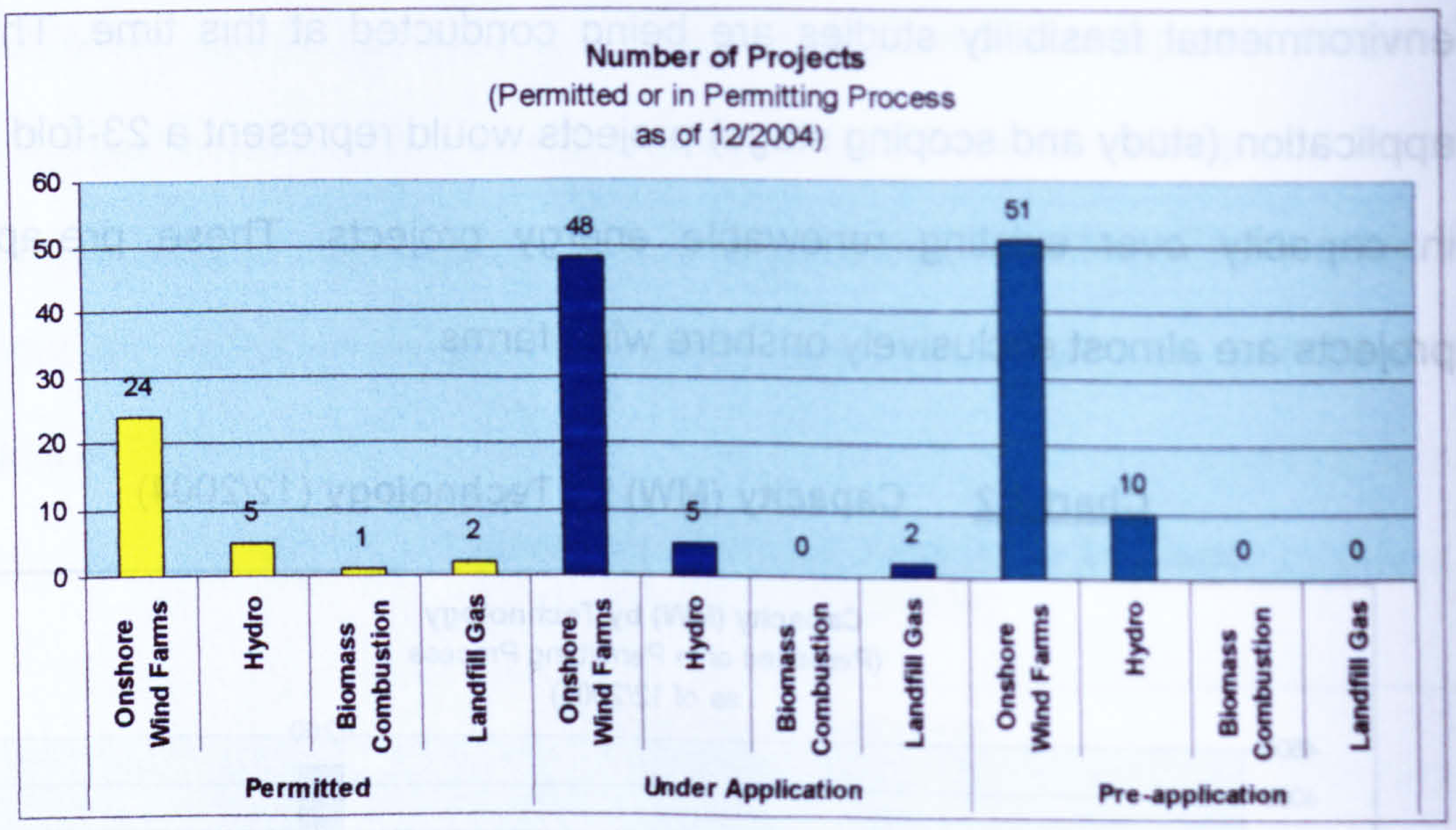
**Chart 2.2** **Capacity (MW) by Technology** (12/2004)




(SE-RED, 2004)

The value of energy projects that are permitted and awaiting construction have a capital cost of approximately £800 million. The construction budget for projects currently in the permitting process is worth approximately £1.6 billion.

**Chart 2.3** **Number of Projects**




(SE-RED, 2004)

The following section will describe and evaluate how the new government policy has changed market dynamics of the power sector, and motivated large amounts of private investment capital to enter the market and expand production of renewable energy.

**Conclusion**

The ROS is fulfilling its primary objective of stimulating the availability of investment funds for deploying new renewable energy projects. The availability of funds has drawn many new firms into the renewables development market, as well as causing established firms to expand their existing operations. The number of projects in a planning or implementation stage in Scotland is growing into the hundreds and may well deliver several thousand MWs of new capacity. The combined revenues from the sale of electricity and ROCs gives renewable generating firms 300% to 400% higher prices per MWh produced than the price received by traditional fossil-fuelled power producers. The theory that economic profits will draw firms into a market is proving true in this scenario.

However, some potential problems and issues have become apparent, as the renewables obligation program approaches the completion of it third year of operating. The vast majority of these new projects will be onshore wind farms, with a small portion of small-scale hydro projects, and minimal amounts of all other technologies. Only those technologies which were on the cusp of being economically competitive have been promoted and deployed by commercial enterprises.

The ROS appears to have been a failure in motivating private industry to invest in greater research and development on technologies that are still distant from profitability, even at the new price levels, which include the ROC premium. Calls from the technology development sector, some might say the demands, for even greater levels of direct government support for basic research are growing.

The industry was expected to take on additional financial risks and invest more in renewable technology research with the potential financial rewards becoming so great.

Wind farms by their nature need access to the wind so are built on high unobstructed hills, so are very visible to the surrounding countryside. This potential change to the rural landscape and environment is a growing concern to some of the Scottish public. Chapter 4 attempts to estimate the value of these impacts which renewable energy projects may have on the environment.

The key policy variables within the ROS are the obligation quota, duration of the obligation, and the buy-out fee. As important as these policy variables are, maintaining independent energy markets and financial markets is critical to success of the ROS, so as allow maximum self-determination of business firms in their individual optimal behaviour and decision-making. How these different variables interact and the stability of the market is of some concern. Chapter 6 presents a model of the strategic interactions between two firms operating under government renewables obligation program and their response to changes in the obligation quota and buy-out fee.

# Chapter 3

## Literature Review

**Chapter Sections**

## Introduction to Renewable Energy Literature

The economic literature on renewable energy is vast. Many fields of economics must be included to fully discuss issues about the use, development, and consequences of deploying renewable energy technologies. Power economics, energy economics, information and knowledge transfer economics, environmental and resource economics, and political economy must be included for any comprehensive discussion.

Also, a working knowledge of power systems engineering is necessary, as the physical limitations of power production, transmission and distribution have explicit physical limits. Many simplifying assumptions which are commonly used in economic analysis would make the findings invalid if the physical reality of the engineered system were not correctly modelled.

The author does not attempt to include all this information or review the literature in this thesis.

The review presented in this chapter will generally limit itself to a discussion of literature that has used environmental economic analytic methods to examine questions about renewable energy issues. Also, included is literature which assisted in understanding the non-quantitative preferences of the public and choice experiment respondents. This consists principally of public opinion surveys.

## Public Opinion Surveys

There have been numerous surveys in Scotland and the United Kingdom which have examined the public's perception and preferences for renewable energy. Findings from several such surveys are presented and discussed below.

Understanding people's preferences, before the choice experiment is conducted is important to the investigative process. The choice experiment is an attempt to go from quantification of people's opinion (and possibly strength of opinion) to valorising that opinion through stated preference analysis.

The most definitive public opinion survey conducted to date in Scotland was commissioned by the Scottish Executive, Scottish Natural Heritage and the Forestry Commission. The survey, *Public Attitudes to the Environment in Scotland 2002* (referred to as the PAES study), was conducted by the Social Research department within the Scottish Executive (Social Research, 2002). The sample includes interviews from over 4000 persons in Scotland.

Portions of the survey findings are presented below with discussion of how the findings relate to the study in Chapter 4. Other surveys which have been conducted are also presented to give comparison.

Table 3.1 below, show that wind and solar power had recognition levels equivalent to that of major power sources like coal and hydro. Nuclear power was the most recognized of all sources for electricity. This information helps to create an *a priori* expectation of what context and energy sources respondents will consider when faced with a choice experiment that involves renewables and traditional power sources.

**Table 3.1 Public Awareness of Electric Power Generation - Technologies**

PAES - Survey Question: *Before today, which of the following ways of generating electricity had you heard of?*

| Technology | Percentage Aware |
|---|---|
| Nuclear power stations | 90 |
| Coal and oil fired power stations | 85 |
| Hydroelectric power | 87 |
| Wind power | 84 |
| Wave power | 57 |
| Solar power | 82 |
| Wood (or other plants) used as a Fuel to generate electricity | 47 |
| Gas used as a fuel to generate Electricity | 63 |
| Combined heat and power from Industrial processes | 41 |
| None of these | 0 |
| Don't know | 1 |

N = 1989 (Social Research, 2002)

One of the most relevant findings was the low recognition of natural gas, which provides 25% of total electricity production. It is also the principle means by which electricity demand growth has been met for the last 15 years. Gas was the stated energy source for electricity in the "neither" profile used in Chapter 4.

In a national survey conducted in England, Wales and Scotland, "Attitudes and Knowledge of Renewable Energy amongst the General

Public: Report of Findings August 2003" (referred to as the A & K study) (TNS, 2003). Knowledge of specific renewable energy technologies varied considerably between individuals. Whilst 44% of the survey sample claimed to know a lot or a little about solar power, this was only 10% for biomass energy. Less than 10% of the general public claimed to "know a lot" about any of the renewable energy technologies.

Although perceived levels of understanding were fairly low across all technologies, solar, hydro-electric and onshore wind power were best understood (with 44%, 41% and 39% claiming to know a little or a lot about each of them, respectively). Marine and biomass technologies were unknown to many: over three-quarters of respondents were not aware of or knew only very little about each of these. It is therefore perceptions of solar, hydro and onshore wind power that currently drive opinion of renewable energy in general.

**Table 3.2** **Public Awareness of Electric Power Generation – Attributes**

PAES - Survey Question: *Which of the following statements would you say applies to generating electricity by each method?* (Percentage of yes responses)

| Statement | Nuclear Power | Coal & Oil | Natural Gas | Hydro | Wind Power | Other Renewables |
|---|---|---|---|---|---|---|
| Very expensive | 35 | 21 | 15 | 16 | 10 | 13 |
| Uses up natural resources that will run out | 8 | 70 | 51 | 5 | 2 | 3 |
| Produces greenhouse gases | 29 | 37 | 38 | 5 | 1 | 1 |
| Does not pollute air or water | 4 | 3 | 5 | 37 | 59 | 46 |
| Cannot generate a supply power at all times | 2 | 5 | 4 | 16 | 42 | 34 |
| Creates a lot of noise that affects local people | 11 | 17 | 7 | 14 | 13 | 2 |
| Produces dangerous wastes | 73 | 22 | 19 | 5 | 0 | 1 |
| Is an eyesore | 35 | 26 | 17 | 10 | 17 | 4 |
| Means energy can be produced on a small scale, close to where it is used | 1 | 4 | 3 | 19 | 39 | 32 |
| None of these | 1 | 1 | 3 | 5 | 3 | 3 |
| Don't know | 11 | 12 | 17 | 20 | 12 | 22 |

N = 1989 (Social Research, 2002)

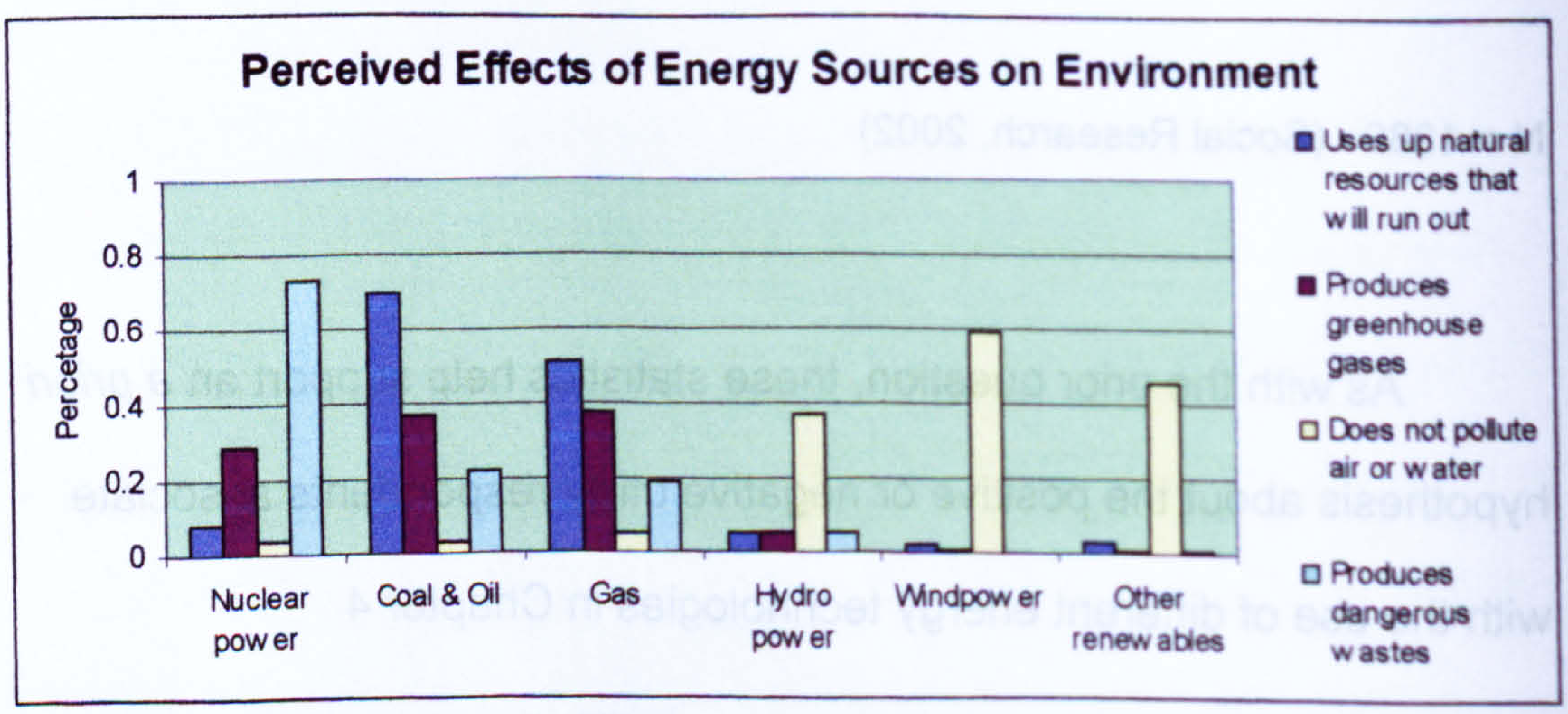
As with the prior question, these statistics help support an *a priori* hypothesis about the positive or negative utility respondents associate with the use of different energy technologies in Chapter 4

Four particular attributes from the list in Table 3.2 are of special interest:

- Produces greenhouse gases
- Does not pollute air or water
- Is an eyesore
- Creates a lot of noise that affects local people

These perceived attributes may be used to predict the welfare changes estimated for hypothetical renewable energy project profiles created in Table 4.7 Welfare Changes from New Renewable Energy Projects. The first two statements relate to the air pollution attribute, the third is related to landscape change, whilst the last statement shows that similar portions of respondents consider wind farms to have approximately the same noise levels to that of other major power stations like coal, nuclear and hydro. This information contradicts the focus group finding for the choice experiment, which showed that noise was not a concern in regards to renewables.

**Graph 3.1 Perceived Effects of Energy Sources on Environment**




N = 1989 (Social Research, 2002)

The A & K study (TNS, 2003) found comparable portions of the general population agreed with similar statements to those use in Table 3.2. The vast majority of respondents (93%) agreed that "using renewable energy sources is a way of looking after our children's future". This statement lends support to the expectation of finding an endowment effect in the choice experiment.

Agreement exceeded three-quarters of the A & K sample for these statements: "renewable energy schemes are less polluting than burning fossil fuels"; "there are more advantages than disadvantages to using renewable energy" and "renewable energy schemes are less damaging to the landscape than fossil fuel generating plants".

Encouragingly, almost two-thirds of respondents disagreed that "all renewable energy schemes are unattractive" once again reflecting the generally positive attitude towards renewable energy. Unfortunately, there is no breakdown between nations to see the exact Scottish proportions to these statements.

In excess of 90% of the public sample stated that renewable energy was a "very good" or a fairly good idea. Very few respondents (1%) described renewable energy as a bad idea. Almost two-thirds of the general public felt that it is "much better" to use renewable energy sources than fossil fuels and a further 21% felt that it is "a little better".

The A & K survey asked a follow-up question of persons who rated renewable energy as a "very good" or "fairly good" idea. The respondents were asked why they believed renewables were good. Table 3.x shows the most common responses.

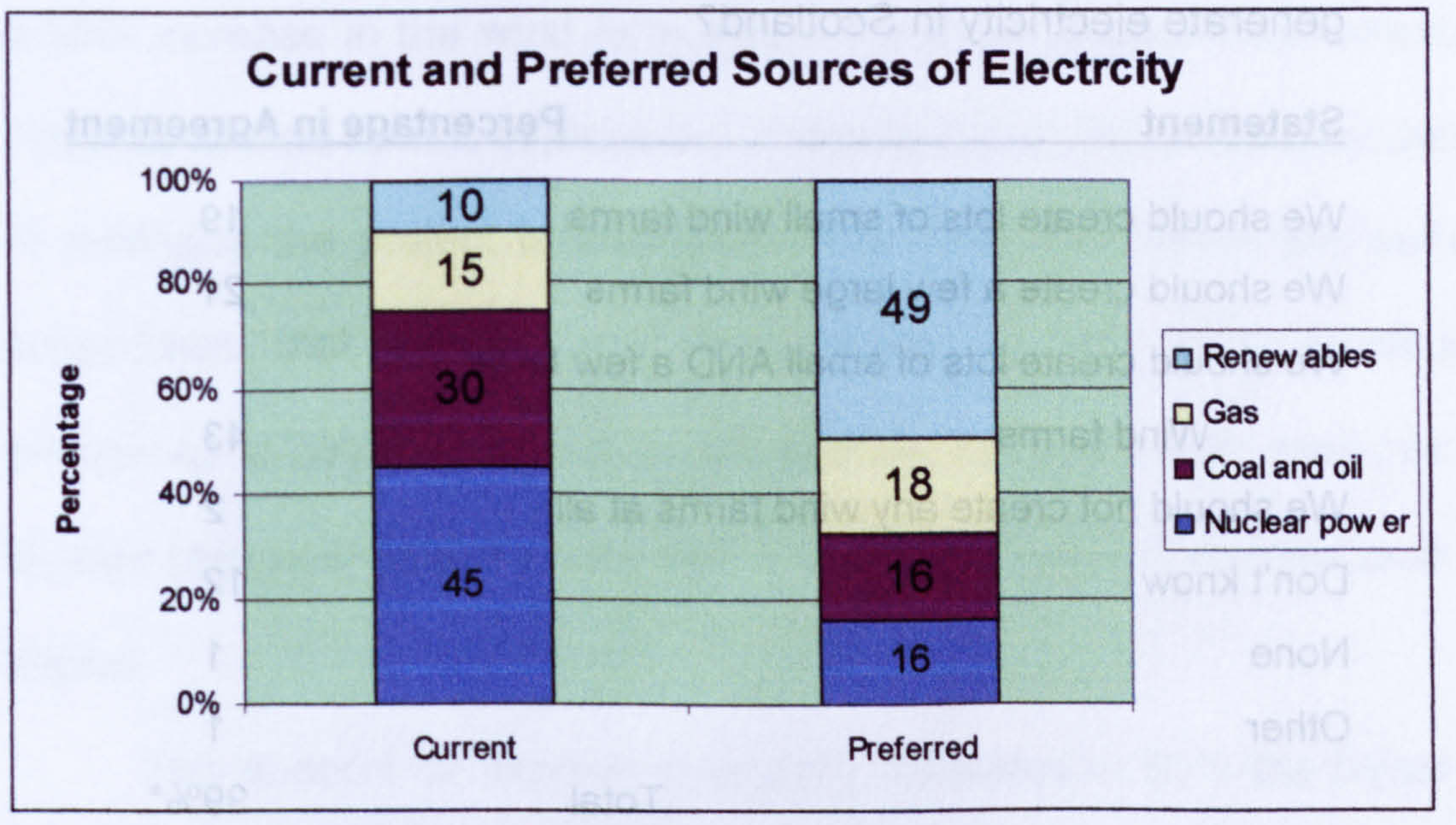
**Table 3.3** **Reasons for positive opinion of renewable energy**

| Reason for Positive Rating | Total % |
|---|---|
| Environmentally friendly | 28 |
| Less pollution/ greenhouse gases | 11 |
| Cleaner | 5 |
| Oil/coal/fossil fuel damage environment | 4 |
| Less/no waste | 2 |
| Safer/safer to produce/safer for the public | 2 |
| **Any environmental benefits:** | **47** |
| Fossil fuels/other resources will run out/are finite | 18 |
| Save fossil fuels/don't use up resources | 13 |
| Think about the future/for the future/in the long term | 4 |
| **Any "for the future" benefits:** | **40** |
| Natural/natural resource | 8 |
| It won't un out/can use again and again | 8 |
| It's replaceable/renewable/sustainable | 5 |
| Available/accessible/plenty of it | 3 |
| **Any sustainability benefits:** | **25** |
| Costs less/cheaper/cost effective | 12 |
| Its free/its free after its been set up | 2 |
| Economical | 2 |
| **Any economic benefits:** | **16** |
| An alternative/new idea/new source/progress | 5 |
| Better than current methods | 2 |
| Don't now | 2 |

Base: General public sample respondents who stated renewable energy was a good idea, N = 1206.
(TNS, 2003)

**Graph 3.2** **Preferred Technologies for Electricity Production**

PAES - Survey Question: *How much energy do you think SHOULD be generated by each of these methods?*




N = 1989 (Social Research, 2002)

The above graph illustrates the different ratios of current technologies used to produce electricity and the public's preference for which technologies should be used and their relative contribution.

There is a high endogenous preference for renewables expansion over all fossil fuel and nuclear sources.

The choice experiment presented in Chapter 4 does not examine the issue of cumulative effects from multiple renewable energy projects through out Scotland; rather it examines the attributes of individual projects, in isolation from any other facilities.

**Table 3.4 Public Preference for Wind Farms in Scotland**

PAES - Survey Question: Which of these statements comes closest to your view on wind farms being used to generate electricity in Scotland?

| Statement | Percentage In Agreement |
|---|---|
| We should create lots of small wind farms | 19 |
| We should create a few large wind farms | 21 |
| We should create lots of small AND a few large Wind farms | 43 |
| We should not create any wind farms at all | 2 |
| Don't know | 12 |
| None | 1 |
| Other | 1 |
| Total | 99%* |

* Does not equal 100% due to rounding error.

N = 1989 (Social Research, 2002)

Table 3.4 indicates the public's preference for how widespread deployment should occur. However, the scenarios ranked above do not co-inside with the welfare values derived in the CE in Chapter 4. The implicit prices derived in the choice experiment estimated large and significant compensation would have to be paid for large onshore wind farms and a relatively small WTP for a moderate onshore wind farm.

In 2003, MORI Scotland, a major public research firm in Scotland, conducted a survey of persons living close (within 20km) to wind farms in Scotland. 1,810 adults were questioned about their perceptions and expectations prior to the wind farm(s) being constructed in their area and how they currently feel about the projects (MORI, 2003).

Important findings from that research address many of the fears over negative environmental changes that people believe may occur.

The first finding is that over half (54%) of the people would support a 50% increase in the wind farm size if it was proposed. This indicates that once a wind farm is in place the marginal impact on near by residents of enlarging the project is negligible. From this information the author conjectures that people will demonstrate a high and significant willingness-to-pay to keep landscape pristine, but pay lesser amounts to change (mitigate) projects from high or medium impact to a lower level of impact.

This support for expansion actually increases to 65% the closer in distance respondents live to a project. However, respondent's support does fall to around 40% if the proposed wind farm expansion is to double the size.

82% of respondents living close to wind farms support an increase in the amount of electric power generated from wind farms in Scotland.

This support for wind farms corresponds to the finding of the choice experiment which found different environmental preferences between rural and urban households. Wind farms will generally be located in rural areas and the rural population reveals a willingness-to-accept some development but not at a high impact level.

**Diagram 3.1**

**Charts 45 and 46 from Attitudes and Knowledge of Renewable Energy Survey**

**Chart 45**

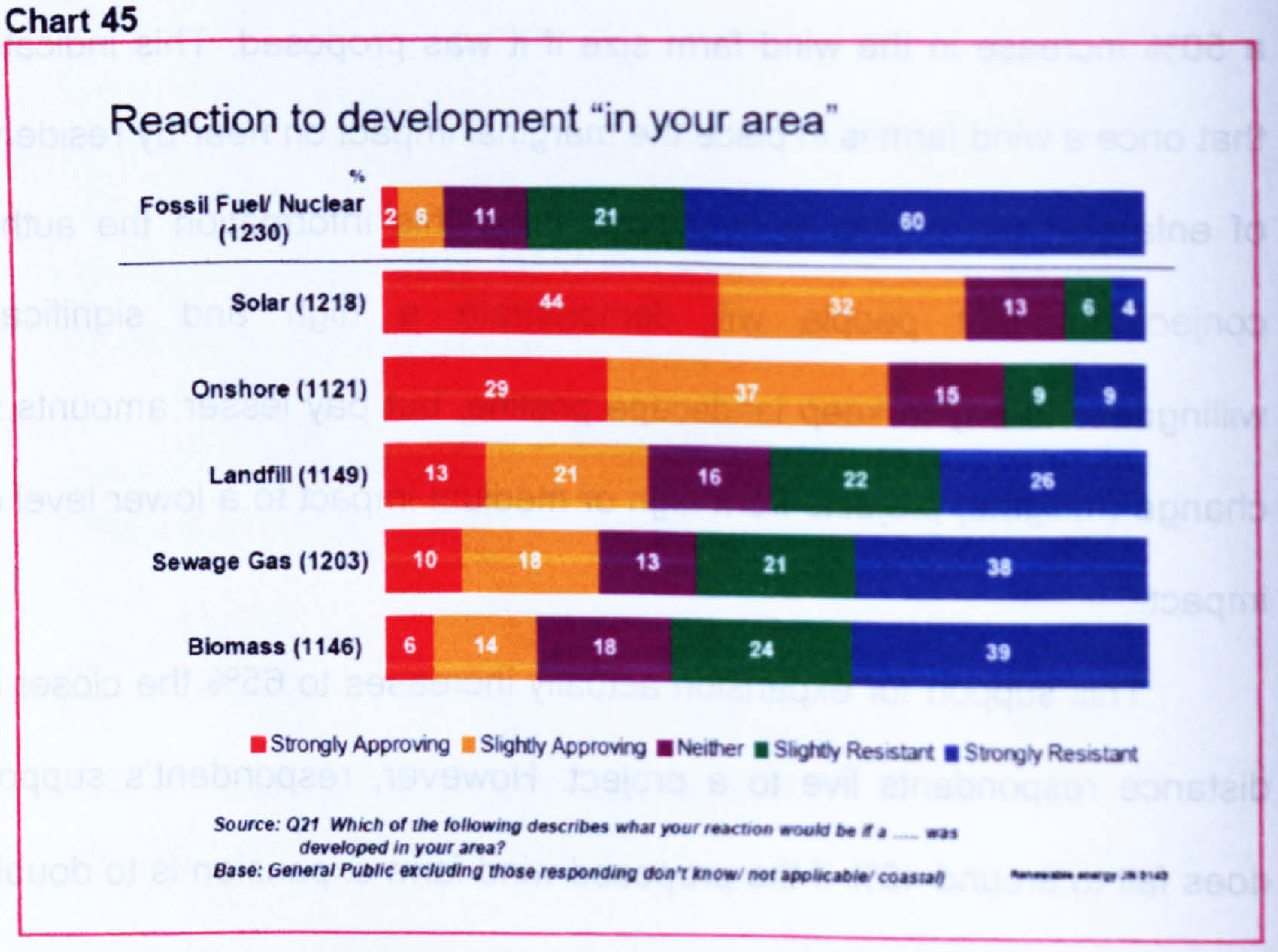
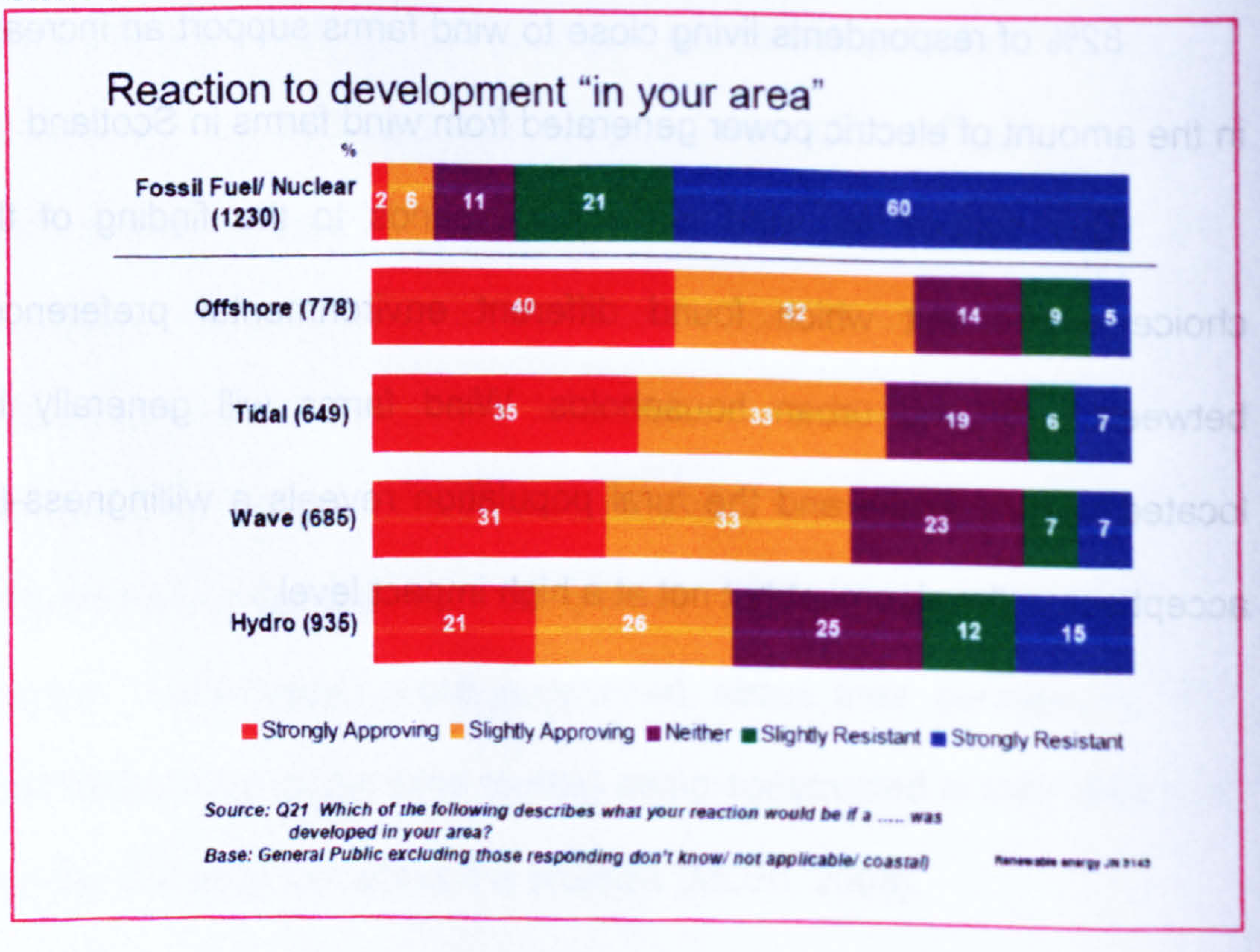



**Chart 46**



The Attitudes and Knowledge of Renewable Energy survey went further than any other opinion researchers in trying to determine the difference between agreeing with renewables because of the social pressure to agree (yea-saying) and the actual willingness to accept a renewables project near a respondent's residence. Respondents were asked; "*Which of the following describes what your reaction would be if a ... (renewable technology)... was developed in your area?*" The results are presented in the following charts from the report (TNS, 2003). Alternative energy facilities were also presented to gather a comparable status quo baseline. The status quo consists of the power plants currently in use.

## Stated Preference Studies Relating to Renewable Energy

Most research conducted by environmental economists has concentrated in two areas; issues relating to wind farms and green pricing of electricity without regard to generation technology. As a result, there are few environmental valuation studies directly comparable to the study presented in Chapter 4. All comparable studies, except one, are solely oriented toward wind farm valuation.

### Environmental Impacts

There is a limited amount of quantitative research into changes that occur in household utility from the construction of renewable energy projects with the resulting change in environmental amenities.

Stated preference studies that have examined the environmental impact of renewable energy development are by Alvarez-Farizo and Hanley (2002), EK (2002 and 2005) and Hanley and Nevin (1999). All these studies used stated preference valuation methods to estimate the environmental impact of wind farms.

Alvarez-Farizo, et al, used potential wind farm development in a geographical area of interest in the north of Spain, to compare estimated implicit prices derived by two survey techniques, choice experiments and contingent rating. The choice experiment survey used three environmental attributes, two the same as in Chapter 4 and one new attribute, plus a standard monetary attribute. The former attributes being the impacts on "landscape" and "habitat and flora" (vs. impacts on landscape and wildlife in Chapter 4) and the later attribute being impact on "cliffs", an important geographic feature. Binary coding was used for the environmental attributes, with the coding indicating rather the quality was either protected from impact or would be lost by impact from a wind farm project.

While the implicit prices are not directly comparable with Chapter 2, some general observations can be made. Wildlife and landscape impacts were statistically significant in both studies, and wildlife impacts were given a higher value than landscape impacts. The contingent rating survey gave the same ordering and statistically significant results as the choice experiment, but had monetary values for landscape and wildlife approximately 45% lower. It was proposed that the survey respondents did not pay as much attention to the price variable in the choice experiment as in the contingent rating survey.

Ek (2002) used a choice experiment to estimate the value given by Swedish households to certain wind farm characteristics. 1000 households were sent a mail survey with descriptive information about wind farms, 6 choice sets and a questionnaire about the respondent's environmental attributes and socioeconomic characteristics. The author used four non-monetary attributes of wind farms: noise level, location, turbine height, and size of wind farm. Household electricity prices were as the monetary attribute. The preliminary statistical analysis failed the IIA assumption so a random effects binary probit model was used to analyse the survey data.

The implicit prices derived by this survey have similarities to the results derived in Chapter 4. Attributes that increase the degree of landscape intrusion create a negative WTP for Swedish households just as in Scottish households. When wind farms are large or located in the mountains, electric power costs would have to decrease to compensate households for the negative change in utility. Households revealed a willingness-to-pay to have wind farms be small or located offshore. Values estimated for noise and height of wind turbines were small and not statistically significant.

Hanley and Nevin (1999) used two methods to evaluate the potential impacts on the local environmental in a rural Scottish area, Assynt, in North West Scotland. Three possible renewable energy options were proposed: a three-turbine wind farm, a small-scale hydroelectric scheme and a small biomass generating station. The two survey methods used were a visitor impact analysis and a contingent valuation study of resident's preferences.

The impact analysis estimated in monetary values of changes in tourism rates would be affected by renewables development. The least cost scenario was "no build" and the status quo would continue. The implied ranking, from least costly to most costly, of the three possible projects is wind farm, small-scale hydroelectric then biomass station. It was noted that the tourists preferred any project be community-led, as this would facilitate greater local income, better represent local resident's desires for their community, and decrease the possibility of failure. Tourism is a small sector of the economy in the study area, but was growing, so any renewables project had the potential to effect long-term prospects for the Assynt area.

The CV study resulted in implied community WTP rankings of: small-scale hydroelectric scheme, wind farm, then biomass generating. The first two projects had similar WTP values of £14,282 and £13,585, respectfully. The biomass project's estimated WTP was less than half that of the other two projects.

Other findings in this study showed preferences were sensitive to the specific location of proposed projects and that opposition was not necessarily related to the type of technology, also that jobs creation was an important attribute for exchange of environmental amenities.

All of these stated preference studies cited and discussed above concur with the general findings of Chapter 4. That there are negative impacts from the construction of renewables projects. There is agreement that people have willingness-to-pay for decreasing the impact on landscape and view sheds, as well as, to decrease the harm to wildlife that might result from projects. Biomass technology will face difficulties being accepted if jobs creation is not sufficient large.

## Revealed Preference Studies Relating to Renewable Energy

### Hedonic Valuation[1]

The Hedonic Pricing Method estimates economic values for environmental amenities that directly affect market prices of some other good. This method is commonly applied to variations in housing prices that reflect the value of local environmental attributes.

It can be used to estimate economic benefits or costs associated with:

- environmental quality, including air pollution, water pollution, or noise
- environmental amenities, such as aesthetic views, proximity to renewable energy sites, or the opportunity to observe wildlife.

The foundation stone of the hedonic pricing method is Lancaster's Characteristic Theory of Value[2]; the price of a marketed good is related to its characteristics, or the services it provides. For example, the price of a house reflects the characteristics of that house - size, comfort, style, location, number of bed rooms and bathrooms, and aesthetic views, etc.

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[1] The description of hedonic pricing is taken from Ecosystem Valuation by King et al., 2005.

[2] See Chapter 4, section on Economic Theory and Econometric Models.

Therefore, it is possible to value the individual characteristics of a house, or other any good, by examining how the market price people are willing to pay changes when the characteristics change.

The hedonic pricing method is most often used to value environmental amenities that affect the price of residential properties. There are two basic steps to the conducting hedonic analysis:

Step 1:

Collect data on residential property sales in the region for a specific time period (usually one year). The required data include:

- selling prices and locations of residential properties
- property characteristics that affect selling prices, such as lot size, number and size of rooms, and number of bathrooms
- neighbourhood characteristics that affect selling prices, such as property taxes, crime rates, and quality of schools
- accessibility characteristics that affect prices, such as distances to work and shopping centres, and availability of public transportation
- environmental characteristics that affect prices

In the case of renewable energy facilities, the environmental characteristic of concern is the change to visible landscape near the residence or along commonly travelled roadways.

Step 2:

Once the data are collected and compiled, the next step is to statistically estimate a function that relates property values to the property characteristics, including the impact on the view shed. The resulting function measures the portion of the property price that is attributable to each

The hedonic pricing method is relatively straightforward and uncontroversial to apply, because it is based on actual market prices and fairly easily measured data. If data are readily available, it can be relatively inexpensive to apply. If data must be gathered and compiled, the cost of an application can increase substantially.

**Advantages**

- The method's main strength is that it can be used to estimate values based on actual choices.
- Property markets are relatively efficient in responding to information, so can be good indications of value.
- Property records are typically very reliable.
- Data on property sales and characteristics are readily available through many sources, and can be related to other secondary data sources to obtain descriptive variables for the analysis.
- The method is versatile, and can be adapted to consider several possible interactions between market goods and environmental quality.

**Issues and Limitations:**

- The scope of environmental benefits that can be measured is limited to things that are related to housing prices.
- The method will only capture people's willingness to pay for perceived differences in environmental attributes, and their direct

consequences. Thus, if people aren't aware of the linkages between the environmental attribute and benefits to them or their property, the value will not be reflected in home prices.

- The method assumes that people have the opportunity to select the combination of features they prefer, given their income. However, the housing market may be affected by outside influences, like taxes, interest rates, or other factors.
- The method is relatively complex to implement and interpret, requiring a high degree of statistical expertise.
- The results depend heavily on model specification.
- Large amounts of data must be gathered and manipulated.
- The time and expense to carry out an application depends on the availability and accessibility of data.

There has been insufficient time and quantity of communities effected by the deployment of wind farms and other types of renewable energy projects in Scotland and the United Kingdom for any meaningful data to be gathered; there have been insufficient transactions in the real estate market.

A report issued in November 2004 by the Royal Institution of Chartered Surveyors (RICS) presented the findings of a membership survey on their perceived changes in values to residential property and agricultural lands from wind farms. This was not a rigorous quantitative analysis as the number of respondent surveyors who had actually dealt with impacted properties was around 80. (RICS, 2004)

Sixty percent of the surveyors stated that wind farms decrease the value of residential property, but the remaining 40% stated there is no negative impact on property values. Those who stated that there was a negative impact stated the following:

- Negative impact starts when a planning application is made
- Main factors for negative impact are:
  - Fear of blight
  - Landscape change after completion
  - Proximity of property to wind farm
- There is no uniformity to how properties are impacted

Sixty-three percent of property surveyors who responded believed that the value of agricultural lands would experience neutral impacts from the construction of wind farms. Although it is unclear if the RICS repost is discussing wind turbines built on the property being valued or on property in the view shed. For turbines located on the property being valued, it is a reasonable expectation that the value should increase from rents being collected on the land lease.

The report suggests further research, as experience increases, to find if what if any adverse impacts decrease with more experience and familiarity with wind farms. (RICS, 2004) This relates to the prior discussion about adaptive state dependence in Section 3.1.3 above.

Jordal-Jorgensen (1996) published findings of a combined contingent valuation/hedonic price study that showed the noise and visual economic cost of wind mills in municipalities ranged from less than 0.1 ore per kWh for the contingent valuation up 1 ore per kWh for property values. One observation was that the environmental cost burden was very unevenly distributed within communities. If the hedonic value is applied to those households that actually experienced the visual and noise nuisance it amounts to DKK 982 per year, while unaffected households had little or no environmental cost burden. It was also noted that economies of scale applied to the size of wind farms, with the environmental cost per kWh diminishing as the number of turbines went from one to a cluster to a full wind farm. This supports a policy in Sweden of having a few very large wind farms, which is the opposite of Scotland and the findings in Chapter 4.

The most significant hedonic price analysis to date was conducted in 2003 by the Renewable Energy Policy Project, located in the United States. It examined the change in property values in 30 communities across America that was affected by wind farm construction (REPP, 2003). The sample set consisted of non-impacted comparable communities and communities with properties that were within a 5 mail radius of the projects and within the view shed. Three scenarios were analyzed.

Scenario One was concerned with how property values changed for both the affected view shed and the comparable community, and used data 3 years before and after the project came on line. Scenario two looked only at how prices change before and after the project came on line in the view shed. Scenario three looked at both affected and comparable communities after the projects were on line. Each scenario examined 10 impacted communities.

For the majority of cases within each scenario the property values actually increased faster in the view sheds than the comparable community. Property value increases were found to accelerate in the view shed after the wind farms were built. In several locations the acceleration was 2 to 3 times that of the comparable communities. Of the 30 view sheds analyzed, 26 were found to perform better than the non-impacted communities.

**Payment Methods for Green Energy**

There has been a consistent and very large gap between the prediction of power market surveys and the actual number of households that actually purchase green power from their utility company in a commercial setting. Farhar (1999) reviewed 20 years of utility market research, looking at consumer willingness to pay for renewable electricity. In America, these surveys show that anywhere from over 50% to as high as 95% of households express a willingness to buy renewables, but the reality is 1% to 5% participation rates, with 2% considered successful participation (EERE, 2000) (CRS, 2002). One significant deterrent which has been identified to green power purchases by voluntary participation in commercial markets is that of free riding. Ferguson (1999), Tarnai and Morre (1998), and Wiser (2003) all found that rated based charging of all users of electricity to support greater use of renewables ranged from 30% to as high as 80%, depending on the additional month cost on their utility bill.

Wiser (2003) presents research findings with direct application and validation of the ROS program currently operating in Scotland. Using a contingent valuation study the following was found:

- Collective payment methods have slightly higher WTP values than voluntary payments. This is attributed to the respondent recognition of free riding.
- Private industry provision of additional renewables generation has a higher WTP than for government provision. This suggests a belief in more efficient and effect provision by commercial interests.
- Individuals thought their WTP was higher than other respondents.
- Those respondents with a WTP for renewables anticipate up to twice as many total households would also be willing to pay, as those who are not WTP. This can be interpreted as support for the bandwagon effect.

All of these findings support the current structure of ROS. All consumers of electricity share in the additional cost from the renewables obligation and private industry is using the market for ROCs and investment capital to determine which renewables projects are to be built.

**Value of Wildlife**

Wildlife has been shown to produce two types of economic value: 1) use value - derived from viewing, hunting and fishing, or any activity which has direct interaction with the fauna; and 2) existence value - occurring to both users and those not actually using wildlife but who have an interest in it (Stevens, et al., 1991).

Existence value was first introduced in the 1960' by Weisbrod (1964) and Krutilla (1967). The first author suggested the non-user would pay an option to retain the possibility of future use, whilst the later argued that some rational people just derive utility from knowing the natural resource exists. Arguments which supported the utility of existence value are: 1) leaving an endowment or bequest to future generation; 2) knowing other people enjoy the resource; and 3) intrinsic value independent of direct benefit or harm to humans. Stevens (1991) found that existence values were likely to be very large and significant in comparison to use values.

The non-use value may come from the "warm glow" effect on respondents, who derive a moral satisfaction from contributing to a public good, rather that the simply stating the inherent economic value of the good (Kahne and Knetsch, 1992).

Ken Willis (1990) in a contingent valuation study found substantial positive values for conservation of wildlife and associated land holdings in England. The results indicated that the valuation of wildlife and nature conservation largely depend on the frame of the reference adopted. Willis found that the social costs are considerably less than the financial costs. However, it was also found that user benefits are considerably less than the financial costs, and that non-user benefits must be included to cover even the social costs of nature and wildlife conservation.

A source of heterogeneity in any stated preference study examining wildlife, specifically any analysis which relies on multinomial logit regression[3] (MNL), may come from moral beliefs about the intrinsic right to exist for all animal species. Depending on the strength of belief the impact on any survey results will range from heterogeneity which is correctable by covariates, i.e. a socio-demographic variable for this belief, to having to exclude the respondent as having a lexicographic preference.

[3] Multinomial logit is discussed in detail in Chapter 4.

# Chapter 4

## *Valuing the Attributes of Renewable Energy Investments*

Acknowledgements:

The original work[1] which provided the basis of this chapter was co-authored with Professor Nick Hanley and Professor Robert Wright. We thank the Scottish Economic Policy Network for providing research funding and an anonymous referee for many useful comments.

The principle author is Eric Ariel Bergmann, and responsible for the following parts of this chapter: original concept, study design, focus group design and script, survey design and pilot testing, sample selection and mail-out, data input, statistical and econometric analysis, original draft of findings.

[1] The original work is published in Energy Policy, Vol. 34, Issue 9, pp. 1004-1014, *Valuing the Attributes of Renewable Energy Investments*, by Bergmann, Hanley and Wright.

**Chapter Sections**

## Introduction

Increasing the proportion of power derived from renewable energy sources is becoming an increasingly important part of many country's strategies to achieve reductions in greenhouse gas emissions. However, renewable energy investments can often have external costs and benefits, which need to be taken into account if socially optimal investments are to be made.

This chapter attempts to estimate the magnitude of these external costs and benefits for the case of renewable energy technologies in Scotland, a country which has set particularly ambitious targets for expanding renewable energy. The environmental externalities investigated herein are the impacts on and changes to landscape, wildlife and air quality from deployment of new energy generation sites. Unlike all published research into the issue of impacts from renewables deployment, we do not restrict our investigation to the effects of particular technologies (such as hydro or wind: Alvarez-Farizo and Hanley, 2002; Hanley and Nevin, 1999), but consider impacts applicable to a wide range of renewable technologies. We also consider the welfare implications of alternative investment strategies for employment and electricity prices. The methodology used to quantify these values is the Choice Experiment (CE) technique.

Renewable technologies evaluated for their social welfare implications include hydroelectric, on-shore and offshore wind power and biomass. Welfare changes for different combinations of impacts associated with the different technology investments are estimated. We also test for differences in preferences towards these impacts between urban and rural communities, and between high and low income households.

## Market Failure, Public Goods and Externalities[2]

Stated preference methodologies were developed to estimate the value of goods and services[3] that do not have a functioning market which reveals public or private preferences and monetary values. In particular, there has been a growing need to value non-marketed goods which arise from the production of an economic good. Non-market goods which impose negative impacts[4] on households who were not party to the original transaction or market exchange are of special concern to environmental economists. An examination of these goods is the object of this chapter. Without knowing and incorporating the true cost or benefit of the non-market good, a socially optimal level of production is unlikely to occur, and public welfare will be diminished.

The beginning of this chapter presents an introductory discussion on the concepts of market failures, externalities and public goods.

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[2] The material presented in this section can be found in most all introductory economic textbooks and certainly in all introductory environmental economic textbooks. The author gives specific citations where appropriate, otherwise the material is considered generally available knowledge and no citation given.

[3] Hence forth when "goods" are referred to "services" is included in the context.

[4] Impacts can be both positive and negative in quality. In this chapter the concern was primarily for the negative impacts on environmental goods; landscape, wildlife and air quality. One positive impact from deployment of renewables projects was investigate, employment.

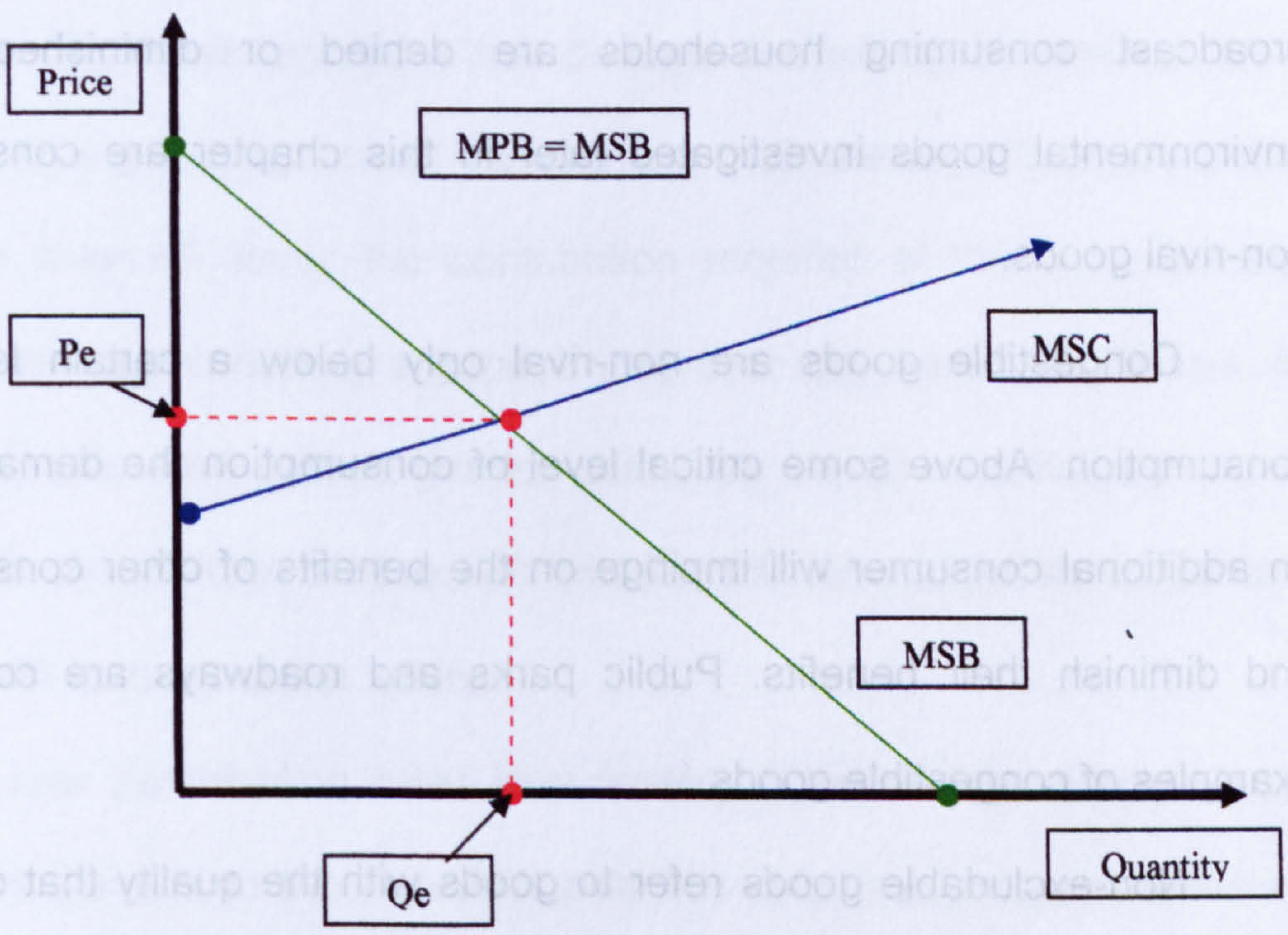
Economics markets commonly fail to include the complete costs imposed on the environment as they function to produce goods for consumers.[5] The failure of markets to accurately reflect and incorporate the true environmental costs of production means that market prices are sending incorrect information, or signals, to market agents as to the scarcity of the good being produced (Varian, 1999). According to neo-classical economics market prices are the key signal to producers as to what type of product and what quantity of output the firm should produce and which production inputs should be used by the firm. Households use market prices to decide what and how much to consume, as well as, how much labour to provide (sell) to business firms. When either party to a market transaction makes decisions based on a price which is an inaccurate reflection of the true private and social costs, than a socially inefficient outcome is likely to occur (Varian, 1999).

Socially inefficient outcomes are defined as non-Pareto optimal outcomes. A Pareto optimal outcome is said to occur when it is no longer possible for trades or exchanges in the marketplace to occur that would make some individuals better off without making some other individuals worse off (Mas-Colell, Whinston and Green, 1995). In the simplest interpretation of Pareto optimality, it can be stated that there is no waste in the economy or society.

[5] The author observes that market prices for most all goods or services are unlikely to reflect the full environmental cost of pollution from the fossil fuel or nuclear energy consumed in the production or distribution of goods or services. Therefore, firms over produce and consumers over consume as a result of these unaccounted for costs.

Two conditions must be met for market prices to accurately reflect the costs of producing a good or service. The market supply curve must represent the marginal social costs (MSC) of producing the good. And the market demand curve must represent the marginal social benefits (MSB) of consuming the good. If either households or firms receive benefits, or incur costs, that are external to the market then the market transaction price will fail to reflect the Pareto optimal level of trade.

**Diagram 4.1 A Well Functioning Market (no market failure)**




A market is said to be functioning well (presenting true and accurate information) if the equilibrium price ($P_e$) and quantity ($Q_e$) coincide with the equilibrium price and quantity as determined by the marginal social benefit (MSB) and marginal social cost (MSC) curves. The above market is Pareto optimal and efficient.

If a market does not meet the Pareto optimal criteria than a market failure is said to have occurred. Public goods and economic externalities are two common sources for utility and production decisions by households and firms to be different from the socially optimal level, thus ensuring market failure.

A public good is a good which is non-rivalrous and non-excludable. Non-rivalrous refers to a good whose benefits do not diminish as it is consumed by any single individual. Every consumer can benefit from the good without diminishing other consumer's benefits. Radio broadcasts are an example of a non-rivalrous good; no matter how much a single household consumes (listens) to the radio, no benefits to other radio broadcast consuming households are denied or diminished. The environmental goods investigated later in this chapter are considered non-rival goods.

Congestible goods are non-rival only below a certain level of consumption. Above some critical level of consumption the demands of an additional consumer will impinge on the benefits of other consumers and diminish their benefits. Public parks and roadways are common examples of congestible goods.

Non-excludable goods refer to goods with the quality that once it has been produced it is impossible, or at least very difficult, to prevent consumption of the good by any individual consumer. Lighthouses are a standard example of a non-excludable good; an environmental good which is non-excludable that arises from private production is improved air quality from commercial forestry.

Non-excludability can lead to the problem of free riding. Free riding occurs when one individual pays the cost for a beneficial good (or mitigation of a negative good) yet other consumers share in the benefits and enjoyment of the good without paying a fair share. Fairness is a subjective standard by which to judge market failure! The common empirical standard by which economists judge free riding to be a problem is when public goods are under produced so less than optimal benefits accrue to society, or when public goods are over consumed causing less than optimal benefits for society (Varian, 1999).

Free riding can also make the identification of the market demand curve for public goods more difficult. Consumers who are free riding have an incentive to mis-represent their demand and willingness-to-pay (WTP) for a public good. By under representing their demand, free riders may believe they will lower the contribution required of them, i.e. through taxes, for the provision of a good. If they over represent their demand for a good, they may believe greater quantities will be supplied without an increase in their own contribution. Mis-identification of the social demand curve will lead to market failure.

Low participation rates in voluntary green energy programs are partially blamed on the free rider problem by some firms in the electric power industry (Farhar, 1999; NREL, 2001). Thus, the private provision of environmentally clean electric energy, which has a significant public benefit, is under produced. See Chapter Three, section on green energy literature for more details of green energy programs.

Some public choice theorists advocate government intervention and state provision of public goods as a way to solve the public goods problem (Stiglitz, 1988). However, in practice the information problem (figuring out how much provision is optimal) and the incentive problem (making it in someone's interest to provide exactly that amount) are unsolved issues, so public goods will still tend to be produced at suboptimal levels even when the government provides them (Stiglitz, 1988).

To determine the efficient level of a public good the aggregate demand curve and the aggregate supply curve must be known. The aggregate supply curve for a public good is derived by the opportunity cost of resources foregone, as example, improved air quality requires firms to forego disposing of waste into the air by some means, waste treatment, pollution prevention, recycling, or reducing production. The aggregate supply curve of healthy air can be seen as the marginal cost of abatement of waste disposal into the air.

**Diagram 4.2** **Vertical Summation of Marginal Social Benefits Curve**

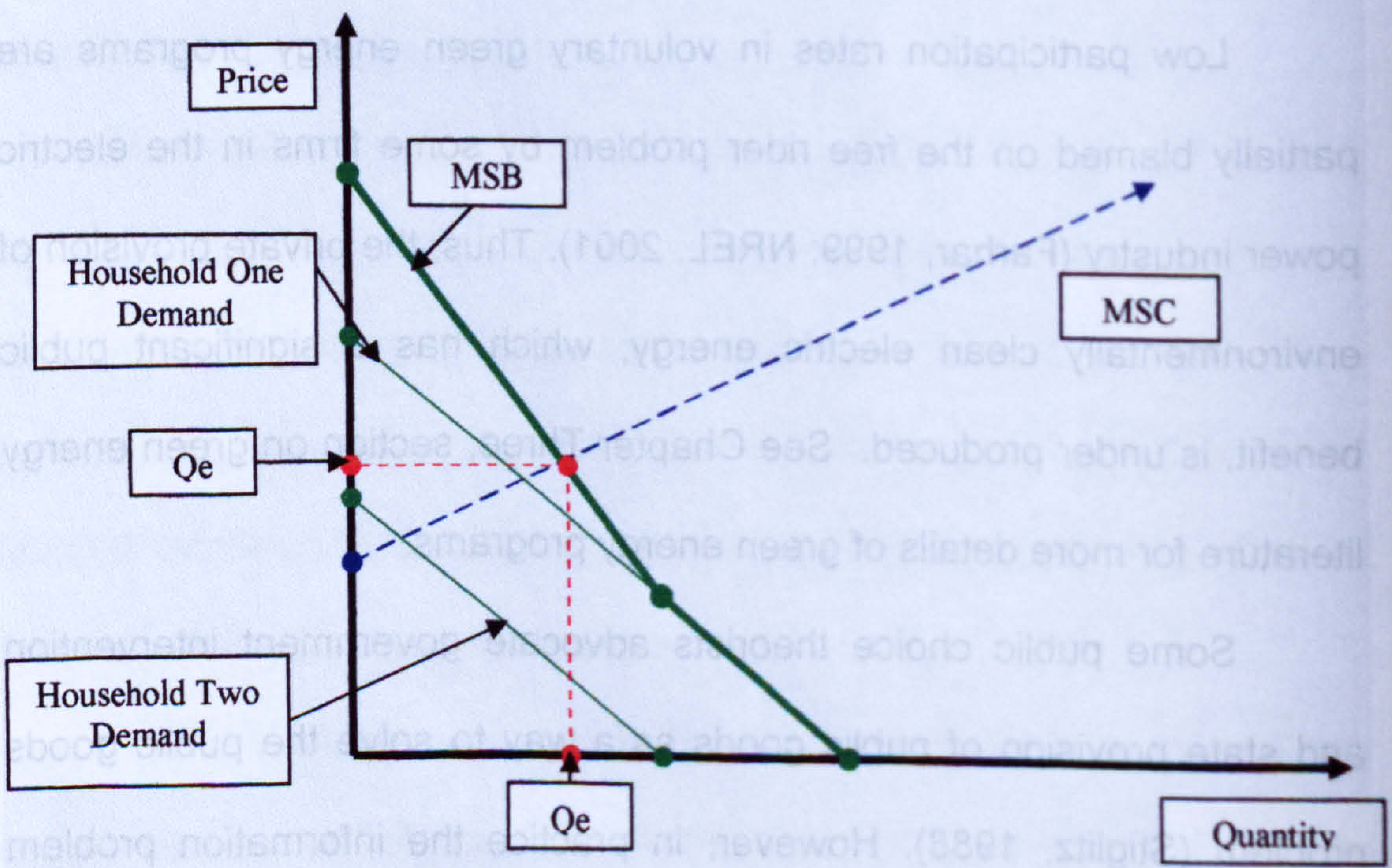


Diagram 4.2 illustrate the same equilibrium conditions as seen in Diagram 4.1 but demonstrates that the MSB (public demand) curve is the summation of multiple households. This vertical summation is possible because of the non-rival nature of the public good.

The demand curve for a public good is derived by adding up the price each individual is willing to pay for each unit of the good and across all individuals sharing in the consumption of that unit. The price of each unit is added vertically for each consumer of that unit. This vertical summation is possible because the good is non-rival. See Diagram 4.2 above.

Firms have no marginal cost for disposing of their waste into the environment if open access exists. So the firm's demand for tipping waste into the environment is equal to the marginal benefit of the costless tipping. The firm's demand can also be described by the inverse, which are avoided costs the firm would have to pay for abating the pollution. The cost to the firm is called the marginal private cost (MPC); this is not the true and accurate social cost or MSC. The difference between MPC and MSC is called the marginal external cost (MEC). If the MEC is negative then a negative externality is said to exist. If the MEC is positive a positive externality exists. Scottish forestry again provides as an example of a positive MEC.

In Diagram 4.3 below, the case of a positive MEC is illustrated. The social good created by expanded forestry is greater that the benefits incurred by the private firm or individual who grows the trees. For this reason there is under production of the socially optimal quantity of forests, $Q_{e(MSB=MSC)} > Q_m$, which motivates the Scottish Executive to give subsidies to private firms and individuals to increase the planting of new forests (CJC, 2004). The same illustration can be used to explain the creation of the ROC program in Scotland; the desire for increased production of renewable energy.

**Diagram 4.3** **Marginal Social Cost versus Marginal Private Costs**

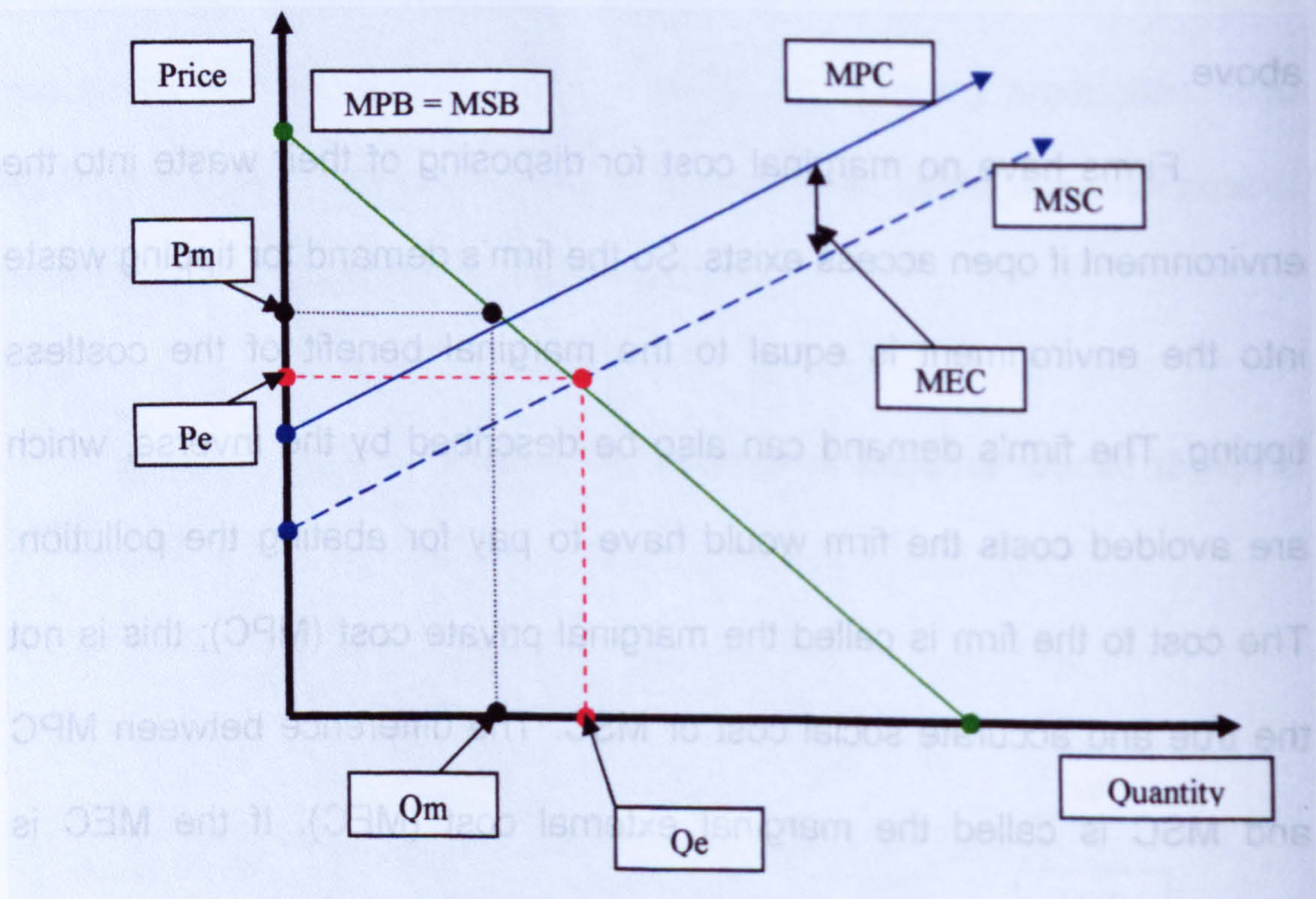



Diagram 4.3 illustrates the MEC and under production (Qe < Qm) of a good that has positive externalities and public benefits.

One possible method of intervention, if a public good is being under provided through the existence of negative externalities, is to change the goods non-excludable characteristic to one of excludability. This may be difficult if a large number of consumers or firms are involved. The transaction costs (or enforcement costs) may be so expensive that no intervention is economically feasible. Open access to the deteriorating good is allowed until the social benefits of improving the good is greater than the transaction costs of excluding firms, or consumers, from using the public good for private benefit. Using the prior air pollution example, using the air to dispose of waste will continue until the loss of social benefits (social cost) is great enough to justify the transaction or protection costs which will be incurred when the government acts.

**Scotland as a Case Study**

The economic reasons for Scotland developing renewables are multifaceted. The first reason is that renewable energy projects by their very nature should be highly sustainable. Economic development which can be sustained without diminishing the country's natural or human resources are a priority to the Scottish governments (Sustainable Scotland Network, 2005). There is minimal or no resource depletion due to the use of renewables technologies, as compared to gas, oil and coal based energy.

Renewable energy projects, as with traditional fossil fuel projects, tend to be capital intensive, so the opportunity to develop and manufacture renewable energy equipment for domestic use and international export exists (RAB, 2004). In 2001, Vestas, a major manufacturer of wind turbines, announced a manufacturing facility would be opened in Scotland (Scottish Executive 2001), although most capital equipment is currently imported.

There is potential to transfer some of the job skills learned in the North Sea oil industry to the marine renewables sector, which includes tidal, wave, and ocean current power generation technologies, as the offshore oil industry declines (a European Marine Energy Centre was opened on Orkney in 2004 to assist in the advancement of marine energy)(EMEC, 2004). Offshore wind farm development may use this skilled labour pool.

England and Wales will have a more difficult time building sufficient renewables generating capacity to provide adequate non-fossil fuel energy which their populations will require to meet domestic targets (OXERA, 2002). Scotland, on the other hand, has some of the largest renewables potential in all of Europe, and therefore may have sufficient excess supplies to trade south of the border. Finally, rural areas of Scotland, with some of the greatest needs for economic development, will be the location of most all land-based renewable energy projects (Hassan, Gerald and Partners, 2001). These rural communities may well reap many benefits from these long-term projects.

Current scale economies dictate that projects like wind farms and biomass generation plants be 3-5% the size of a traditional 1200 MW coal-fired plant. Even the largest wind farms being planned today are only 20% of this size. Also, because of the intermittency problems of renewable sources, greater quantities (measured by MW capacity) of generating assets are needed because of the lower average load of each renewables facilities. Depending on the technology, renewable energy projects normally require large amounts of surface area to capture the energy in wind, water, solar radiation or biomass, in sufficient quantity to be commercially viable. These projects will likely be dispersed as a result. Thus dozens of communities in Scotland will likely be impacted by renewable energy projects that will be constructed to attain the Scottish Executive's clean energy goal.

**The Choice Experiment Method**

Renewable energy investments in Scotland are thus expected to grow rapidly in the near future. These investments will produce a series of impacts on the environment, the price of electricity, and on employment. Environmental impacts will occur to the landscape and wildlife, as well as changes in air pollution (for example, biomass combustion power plants emit air pollution). Exactly what environmental impacts occur, what happens to electricity prices through changes in cost, and any changes in employment, will depend on the exact investment mix (e.g. the balance between on- and off-shore wind farms; the extent of hydro developments). Taken together, environmental effects, price effects and employment effects can be thought of as the *attributes* of a renewable energy strategy. Knowing something about the relative economic values of these attributes is important if we wish a renewables strategy to (i) take some account of public preferences and (ii) take some account of economic efficiency (benefit-cost) concerns. *Choice Experiments* are an economic valuation method which enables this kind of information to be produced.

## Choice Modelling, Choice Experiment and other Stated Preference Valuation Methods

Choice modelling (CM) originated as an empirical technique to conduct non-market valuation research for marketing, product development, and transportation studies. It is a form of stated preference analysis. There are four types of CM techniques: choice experiments; contingent ranking; contingent rating; and paired comparisons. The unifying concept for all of these CM methods is the theory that all goods may be described in terms of its attributes and the levels of those attributes[6]. As example a landscape may be described in terms of the type and quantity of vegetation, biodiversity, terrain, colours, and human influences such as agriculture and structures. Changing any one of these attribute levels creates a new good. CM focuses on the value of these changes. CM can estimate both use and non-use values of goods (Louviere, 2000). It is important to note that only choice experiment and contingent ranking methods have substantial linkages to standard economic theory for the estimated values to be useful in cost-benefit and other economic analysis.

CM can identify several non-market issues (Bateman et al., 2002) that are of importance:

- Attributes which are significant determinants of value.
- The implied ranking order of attributes.

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[6] Lancaster's Characteristic Theory of Value is discussed later in this chapter.

- The change in value from a change in one or more of the attributes.
- The total economic value of the good.

There are many advantages of CE over other stated preference techniques. CE can simultaneously study several parts (attributes) of a proposed project scenario in the same survey. Contingent valuation (CV) is not capable of doing this. To estimate the value of different attribute levels a CV study would have to design different scenarios for level of the attribute and conduct a new survey for each scenario.

CE is superior in measuring the marginal value of changes in attributes. The marginal values of attributes (sub-parts) of a project scenario can be more useful in a policy context when compared to making decisions based on only knowing the total gain or loss from a project change.

CE studies can eliminate or reduce a major modelling problem associated with revealed preference analysis. Revealed preference studies use actual scenarios, many of which may have attributes that change in a collinear manner, i.e. for landscape vegetation and colour will be associated. Collinearity can inhibit econometric analysis. CE studies are not limited to the use of actual scenarios[7]. Travel cost analysis is also limited by to actual attributes of the scenario under investigation. CE is not limited to the actual attributes of a project but can study levels beyond the upper or lower limits of what exists.

[7] Non-collinearity and orthogonallity are discussed later in this chapter.

CE addresses some of the critics of CV studies, such as yea-saying and strategic answering (Blamey et al., 1999). Some survey respondents say yes to a question that has a politically correct social response, i.e. would you pay for reduced pollution? Strategic answering is when a respondent gives an answer (monetary value) which exaggerates their position on an issue, not an answer which reflects their true personal monetary value. In CE respondents are given a range of values to include in their responses over several choice sets. Respondents are only allowed to include monetary value in relation to other attributes.

There are some disadvantages which arise from the use of CE analysis. Possibly the most significant is issues are the assumption that the sum of the attributes is equal to the whole of the good under study. This additive quality may not hold true in all circumstances (Hanley et al., 1998). This is known as the packaging problem. Two studies (Steer et al., 1999, 2000) of public transportation in London, the Underground and buses, has demonstrated that the sum of individual attributes are valued more than the bundles of improvements in total.

Coinciding with this assumption is a problem of model mis-specification. If any attributes which contribute substantial utility or disutility are not included the relative importance of included attributes may mis-inform policy makers. Any omitted attributes will be captured by the constant term in the model, but the constant term may incorrectly imply an unidentified greater or weaker underlying value for the good.

Value estimates for attributes are sensitive to the design of the CE study. This is true for all other types of stated preference research which depends on surveying the public. Every aspect of the survey design has the potential to influence respondents, such as the included or excluded attributes and levels, presentation media (pictures or words), and if the interview is conducted by mail, internet or in-person.

Two other issues are known weakness of CE. CE does not provide estimates for attributes that are valid when programs may be implemented in a sequential manner. CE modelling assumes ceteris paribus for the value of estimates; sequential changes of attribute levels may invalidate the marginal effects estimates of the model. The final disadvantage for CE analysis is that the complexity of the choice task may prove too difficult. Task complexity is discussed elsewhere in this chapter.

## Economic Theories and Econometric Models

### The Characteristics Theory of Value and Random Utility Theory

Choice Experiments (CE) are based on two fundamental building blocks: Lancaster's characteristics theory of value, and random utility theory. Lancaster (1966) asserted that the utility derived from a good comes from the characteristics of that good, not from consumption of the good itself. Goods normally possess more than one characteristic and these characteristics (or attributes) will be shared with many other goods (Lancaster, 1966). The value of a good is then given by the sum of the value of its characteristics.

Random Utility Theory (RUT) is the second building block. RUT says that not all of the determinants of utility derived by individuals from their choices are directly observable to the researcher, but that an indirect determination of preferences is possible (McFadden, 1973; Manski, 1977). The utility function for a representative consumer can be decomposed into observable and stochastic sections:

$$U_{an} = V_{an} + e_{an} \qquad \textit{(Eq. 4.1)}$$

Where $U_{an}$ is the latent, unobservable utility held by consumer n for choice alternative *a*, $V_{an}$ is the systemic, or observable portion of utility that consumer *n* has for choice alternative *a*, and $e_{an}$ is the random or unobservable portion of the utility that consumer *n* has for choice alternative *a*. Research is focussed on a probability function, defined over the alternatives which an individual faces, assuming that the individual will try to maximise their utility (Bennett & Blamey, 2001and Louviere et al., 2000).

This probability is expressed as:

$$P\,(a \backslash C_n) = P\,[(V_{an} + e_{an}) > (V_{jn} + e_{jn}),\ \forall a \neq j, \qquad \text{(Eq. 4.2)}$$

for all j options in choice set $C_n$; *a* and *n* are as previously described; or:

$$P\,(a \backslash C_n) = P\,[(V_{an} - V_{jn}) > (e_{jn} - e_{an})], \quad \forall a \neq j. \qquad \text{(Eq. 4.3)}$$

To empirically estimate (3), and thus to estimate the observable parameters of the utility function, assumptions are made about the random component of the model. A typical assumption is that these stochastic components are independently and identically distributed (IID) with a Gumbel or Weibull distribution.

**Multinomial Logit (MNL)**

This leads to the use of multinomial logit (MNL) models (sometimes called conditional logit models) to determine the probabilities of choosing *j* options (Hanley, Mourato and Wright, 2001):

$$P(U_{an} > U_{jn}) = \frac{\exp(\mu V_a)}{\Sigma_j \exp(\mu V_j)},\ \forall a \neq j \qquad \text{(Eq. 4.4)}$$

Here, $\mu$ is a scale parameter, inversely related to the standard deviation of the error term and not separately identifiable in a single data set. The implications of this are that the estimated $\beta$'s cannot be directly interpreted as to their contribution to utility, since they are confounded with the scale parameter. When using the MNL model choices must satisfy the Independence from Irrelevant Alternatives (IIA) property, which means that the addition or subtraction of any option from the choice set will not affect relative probability of individual *n* choosing any other option (Louviere, et al., 2000). Modelling constants known as alternative specific constants (ASCs) are typically included in the MNL model. The ASC accounts for variations in choices that are not explained by the attributes or socio-economic variables, and sometimes for a status quo bias (Ben-Akiva and Lerman, 1985).

**The Random Parameter Logit (RPL) Model**

Another econometric approach is the Random Parameters Logit (RPL), which is becoming increasingly popular in applied research. In this approach the utility function for respondent *n* choosing over alternatives *j* ($j$=1,2,...$J$), $U_{jn}$, is augmented with a vector of parameters $\eta$ that incorporate the individual preference deviations with respect to the mean preference values that are expressed by vector $\beta$:

$$U_{jn} = C_j + \Sigma_k \beta_{jk} X_{jkn} + \Sigma_m \gamma_m S_{mn} C_j + \Sigma_k \eta_{kn} X_{jkn} + \varepsilon_{jn} \qquad \textit{(Eq. 4.5)}$$

where $C_j$ is an alternative specific constant ($C_J$=0, for identification purposes), $X_{jkn}$ is the *k*th attribute value of the alternative *j*; $\beta_{jk}$ is the coefficient associated with the *k*th attribute, $S_{mn}$ is the *m*th socio-economic characteristic of individual *n*, and $\gamma_m$ is the coefficient associated with the *m*th individual socio-economic characteristic. Note that socio-economic characteristics are invariant across choice occasions for each individual in the sample, so are interacted with the alternative specific constant. Furthermore, $\eta_{kn}$ is a vector of *k* deviation parameters which represents the individual's tastes relative to the average ($\beta$) and $\varepsilon_{jn}$ is an un-observed random term which is independent of the other terms in the equation, and which is identically and independently Gumbel distributed. The researcher can estimate $\beta$, $\gamma$ and $\eta$; the $\eta$ terms, as they represent personal tastes, are assumed constant for a given individual across all the choices they make, but not constant across people. Random parameter logit probabilities are weighted averages of the logit formula evaluated at different values of $\beta$, with the weights given by the density $f(\beta)$. The probability that respondent *n* chooses alternative *i* is given by:

$$P_{ni} = \int L_{ni}(B)\, f(B)\, d(B) \qquad \textit{(Eq. 4.6)}$$

where $L_{ni}(\beta)$ is the logit probability evaluated at parameters $\beta$. Since the integral (Eq.3.6) has no closed form, parameters are estimated through simulation and maximising the simulated log-likelihood function. In order to estimate the model it is necessary to make an assumption over how the $\beta$ coefficients are distributed over the population. Here we assume that preferences for all the environmental attributes follow a normal distribution, except for the *jobs* and *price* attributes for which preferences were assumed to be homogeneous.

**Implicit Prices or Part-worth values**

The estimated coefficients of the attributes can be used to estimate the tradeoffs between the attributes that respondents would be willing to make. The price attribute can be used in conjunction with the other attributes to determine the willingness-to-pay of respondents for gains or losses of attribute levels. This monetary value is call the "implicit price" or part-worth of the attribute:

Part-worth = - (β non-market attribute / β monetary attribute)

*(Eq.4.7)*

The scaling problem noted above is resolved when one attribute coefficient is dividing by another, as in the part-worth equation, since the scale parameter in the denominator and numerator cancels out.

**Alternative Estimation Methods**

Three alternative estimation methods or models may be useful in analyses of choice data where preference heterogeneity is present and the MNL method cannot be used. They are the nested logit (NL) model, latent class analysis and the random parameter logit (RPL) model.

The nested logit model relaxes the homoscedasticity assumption in the MNL model by subdividing the sample group into subgroups which are based on the observed choices the individual group respondents made in the survey. This subdivision allows the variance to differ across the subgroups, but requires the IIA assumption to be maintained within each subgroup (Greene, 2002).

The nested logit method was rejected for use in this analysis as it was deemed insufficient selection of the "neither" option occurred by respondents. Only 23 of over 800 choice sets had the "neither" option selected; this is less than 3%. There would be little or no distinction between the nested logit models analysed at the first level of subgroup division. Nested logit first branch segregation would be options A and B versus neither, second branch is than between A and B (Hanley et al., 2002). See Diagram 4.4 below.

A second analytical model used to address preference heterogeneity is latent class analysis. The underlying theory of the latent class model argues that individual behaviour depends on observable attributes of the individual respondent and on latent heterogeneity that varies with factors that are unobservable (Greene, 2002). The essential technique used in a latent class model is to divide the sample group into subsets based on respondent socio-economic characteristics. This division can be done endogenously or

**<u>Diagram 4.4</u> Nested Logit Model - Decision Tree**

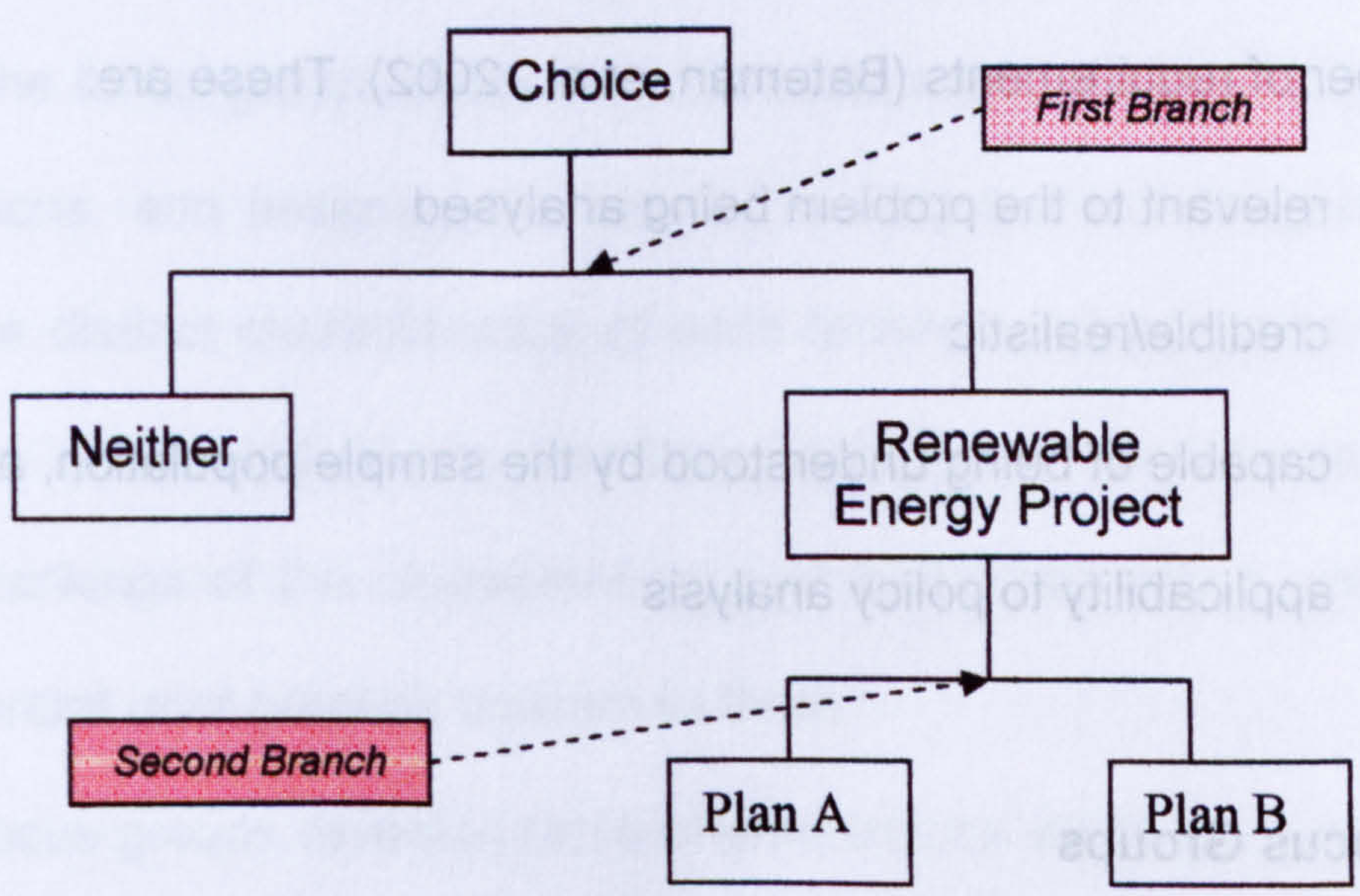


Diagram 4.4 is a Nested Logit Model decision tree for the choice experiment being discussed. The first branching occurs when respondents declare their preference for the status quo (continue on current energy path) or their preference for renewable energy. The second branching occurs when respondents declare which renewables profile they prefer, based on the bundle of descriptive attributes.

exogenously. Latent class models allow for endogenous characteristics to segregate the individual respondents into categories (Swait, 1994). The exogenous method is to hypothesize a source of heterogeneity and than segregate the sample set into subgroups and test for improved statistical significance of the estimates. As with the nested logit model, the division of the full sample into subgroups allows the variance to differ across the subgroups, but the IIA assumption still has to be maintained within each subgroup.

The final method, which has been previously discussed, is the RPL model, which neither assumes nor requires IIA to be valid for analysis.

## Designing the Choice Experiment

### Selection of Attributes

In any choice experiment, attributes must be chosen which meet a number of requirements (Bateman, et al., 2002). These are:

- relevant to the problem being analysed
- credible/realistic
- capable of being understood by the sample population, and
- applicability to policy analysis

### Focus Groups

Identifying a set of attributes, and levels within each attribute, is important to the creation of a rigorous choice experiment design. For this reason two focus groups were conducted with members of the general public (Dewar, 2003). The objective set to each group was the identification of important characteristics[8], or attributes, of 'green electricity' production, without regard to the characteristics being 'good' or 'bad' in quality. The facilitator had each group identify all types of renewable power technologies, and then discuss the good or bad characteristics of each type of technology and facility. Identified technologies were: windmills, hydro schemes (run of river and reservoir); tidal and wave powered; solar (photovoltaic and hot water panels); geothermal (heat pump); many types of biomass or waste combustion, i.e., municipal solid waste, wood and forest residue, animal and organic waste, natural gas from landfills, and fermentation of organics. After the technology was identified, the characteristics of each were discussed and listed on a chart.

Next, the focus groups were separated into small sections of two or three persons, and assigned the task of ranking the technologies and ranking the distinct characteristics of each technology by importance to them as a group. Individuals members were asked to indicate their personal rankings of the characteristics and to indicate which were the most important or of greatest concern to them.

Both focus groups revealed three characteristics which dominated all others. The first characteristic was renewable energy projects must have a low environmental impact, and should reduce or minimize how society changes or pollutes the environment. Another characteristic was that

[8] The author and focus group facilitator used the word 'characteristics', instead of 'attributes', in conducting the focus groups. Discussing "attributes" in preliminary interviews with individuals from the general public appeared to be confusing, while "characteristics" appeared to be better understood.

projects be aesthetically pleasing. This characteristic was a little more contentious as some group members felt that both windmills and reservoirs are pleasing to observe, while other members felt that large man-made structures took away from nature's scenic beauty. The final dominant characteristic was that wildlife should not be harmed any more than it already has been, and projects which improved wildlife should be given greater support.

Less significant characteristics mentioned by individuals, or the sub-groups which were used, were the creation of jobs, the effect on electricity prices, the abundance and sustainability of the resources, and more localized control and responsibility which might be possible with renewable energy projects

### Attributes

Five key attributes were chosen, based on the two focus groups, individual interviews, and on published government statements (e.g. Scottish Executive, 2002b) and academic literature dealing with environment and green energy. The attributes selected for the experiment were:

- Impacts on the landscape,
- Impacts on wildlife,
- Impacts on pollution levels, in particular, air pollution,
- Creation of long-term employment opportunities, and
- Potential increases in electric prices to pay for renewable sources.

Table 4.1, below, presents the attributes and levels as used in the final design. Given the 5 attributes and 17 associated levels, 360 possible profiles exist[9], which was an unfeasible number to employ in the survey. Randomly selected respondents are expected to have limited time and mental concentration they will commit to a survey, so designing a survey which does not exceed those limits is critical to capturing accurate information (Dillman, 2000; Arsham, 2006).

The levels for the environmental attribute were difficult to determined in a rigorous manner and still be able to present then in the survey without in creating excessive learning and education needs by the respondents. Benchmarking the levels to exogenous scientific standards was determined to be unpractical and increasing the likelihood of low response rates. For this reason it was decided to use the qualitative words, high, moderate, low, and slight to describe impacts from renewable energy projects. The interpretation of these words was left to the respondent. The translation of respondent's interpretation of these words to an indexed standard which policymakers can use is an area for further research.

Three primary sources were consulted on criteria to measure the impact on landscape from human initiated change Guidelines *for landscape and visual impact assessment* from the Landscape Institute, *Guidance on Local Landscape Designations* from Natural Heritage

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[9] The factorial is calculated by multiplying the number of levels of each attribute. In this choice experiment the attributes levels are: 4 for landscape, 3 for wildlife, 23 for air pollution, 3 for jobs created, and 5 for price changes. Therefore, 4 * 3 * 2 * 3 * 5 = 360, the total number of profiles possible.

Scotland, and Making Sense of Place Landscape Character Assessment by the Scottish Natural Heritage and Countryside Agency (CSA, 2002; Landscape Institute, 1995; SNH, 2001).

For impacts on wildlife the Scottish Wildlife Trust and the Scottish Environmental Protection Agency (SEPA) were consulted (SWT, 2004; SEPA, 2004). SEPA was also consulted on the air pollution attribute.

**Table 4.1 Attributes and Attribute Levels**

| Attribute | Description | Levels |
|---|---|---|
| Landscape Impact | The visual impact of a project is dependent on a combination of both the size and location. | None, Low Moderate, High |
| Wildlife Impact | Change in habitat can influence the amount and diversity of species living. around a project | Slight improvement, No-impact, Slight Harm |
| Air Pollution | Many types of renewable energy projects create no additional air pollution, but some projects do burn non-fossil fuels. These projects produce a very small amount of pollution when compared to electricity generated from coal or natural gas. | None, Slight ncrease |
| Jobs | All renewable energy projects will create new local long-term employment to operate and Maintain the projects. Temporary employment Increases during the construction phase are not being considered. | 1-3, 8-12, 20-25 |
| Price | Annual increase in household electric bill resulting from expansion of renewable energy projects. An average household pays £270 a year (£68 per quarter) for electricity | £0, £7, £16, £29, £45 |
| **Alternate specific constants** | | |
| ASC-A | Takes value of 1 for Plan A, 0 otherwise. Acts to represent variations that cannot be explained by the attributes or socio-economic variables. | |
| ASC-B | Takes value of 1 for Plan B, 0 otherwise. Acts to represent variations that cannot be explained by the attributes or socio-economic variables. | |

For the jobs attribute two resources were consulted: The Work that Goes into Renewable Energy, November 2001, a report on the job creation associated with the development of renewable energy projects in the United States; and Environment Jobs Scotland: Skills for Renewable Energy in Scotland, which reviewed the skills and training issues facing the renewable energy sector.

The price levels were determined in the following manner:

£0 – the lower limit, only a price increase is predicted from the expansion of renewable power sources.

£7 – the average amount paid by consumers in Scotland who voluntarily participate in a green energy program (Energy watch, 2003).

£29 – approximately a 10% increase in the average amount paid for electricity by household in Scotland in 2002 (Energy watch, 2002).

£45 – an exaggerated upper limit for an energy price increase, used to capture an income effect.

### Selection of Profiles

There are a number of different strategies that may be used to reduce the quantity of choice sets submitted to survey respondents: 1. Reduce the number of levels used within the design; 2. Use a fractional factorial design; 3. Blocking the design; and 4. Using a fractional factorial design in combination with a blocking strategy (Hensher et al., 2005).

Reducing the levels within the design will significantly reduce the size, yet such a reduction has a cost in terms of lost information and observations of incremental changes between levels. As example, using this method the factorial would be lowered to 288 profiles, from 360, by reducing the price attribute from four to five levels, or the factorial could be lowered to 240 profiles if the wildlife attribute was reduced from three to two. Finally, if both attributes were reduced by one level the factorial would be 192 profiles.

Another factorial reduction method uses only the extreme attribute levels, the levels at each end of the attributes range. This design style is known as end-point design (Louviere et al., 2000). All attributes would be binary in nature, with the "best" and "worst" levels being the only possibilities. This procedure would reduce the number of profiles to 32[10], but the information loss would be acute.

Using only a portion of the total profiles is called fractional factorial design. By selecting a smaller and more manageable number of profiles the experiment can be conducted without overloading the survey respondents. However, random selection of profiles will likely produce

[10] The factorial is calculated as (2 * 2 * 2 * 2 * 2) = 36, for five attributes with two levels each.

sub-optimal and statistically inefficient experimental designs (Hensher et al., 2005). To avoid this statistical inefficiency an orthogonal design needs to be used in selecting profiles.

Orthogonallity is a mathematical constraint which requires the attribute levels within each profile to be statistically independent of other profiles (Hensher et al., 2005). Orthogonallity is a condition where zero correlation exists between attribute levels of one profile to another profile. In other words, the change in one attribute in relation to another within one profile is independent from the change in one attribute to another in all other profiles in the selected fraction.

Along with orthogonallity, main and interaction effects must be considered when using a fractional factorial. An effect is defined as the impact a particular profile has upon the respondents choices; it is measured as the difference in means (average log-likelihood of choice) between different profiles (Hensher et al., 2005). The main effect is the difference in the mean of each level of an attribute and the overall or grand mean of the profile, or the marginal effect of a change in an attribute level on the total likelihood of that profile being chosen by the respondents. An interaction effect is the effect upon the response variable, respondent's choice, obtained from combining two or more attributes which would not have been observed had each of the attributes been estimated separately. In simple terms, main effects are the estimation of the individual attributes, ceteris paribas, while interaction effects are the estimation of attributes allowing for changes in one or more other attributes. As example, a main effect would be the change measured for one level of the landscape attribute, while an interaction effect would be the change measured for the same landscape level but coinciding with a change in one of the wildlife attribute levels. Interaction effects require a substantial increase in the number of observations to measure such marginal changes on marginal changes (Hensher et al., 2005; Louviere et al., 2000; Bateman et al., 2002).

The final method to reduce the number of profiles used in a choice experiment is called "blocking" (Hensher et al., 2005). Blocking entails including an additional attribute, the levels of which are used to divide the orthogonal design into separate sections. As example, if an attribute with 3 levels is included in the orthogonal design, the design may be separated into 3 groups based on those sections. The three sections may than be administered separately in the experiment. A factorial with 180 profiles could be broken into three groups of 60 or a fractional factorial with 27 profiles could be broken into groups of nine, the former continuing to be impractical, while the later can improve the experiment.

The two most common methods used to reduce the total number of profiles presented in a choice experiment are fractional factorial and the combination of the fractional factorial and blocking.

In this experiment it was decided to use a fractional factorial design to reduce the full factorial of 360 to 25 profiles that could be used to estimate main effects.

Econometric software, SPSS (VERSION 10.0), was used to select the optimal choice profiles, which were combined to make up the choice sets (choice groups) used in the experiment. This smaller set of profiles was also orthogonally designed, which is a desirable, but not a requirement, of choice set construction. Table 3.x presents the 25 profiles.

All the profiles were examined for rationality. By rationality the author means would an average person believe this profile could actually come into existence. One profile of the 25 was deemed "irrational", profile 26. This profile was composed of all the lowest utility attributes for a household: high landscape impact; slight increase in harm to wildlife; slight increase in air pollution; the smallest amount of permanent employment gain; and the highest price increase in electricity. This profile is dominated by all other profiles generated for this experiment. The problem with this profile was confirmed in pilot tests of the survey instrument, when one respondent questioned, "Who would want the worst case, for the most money?"

Hensher et al., (2005) states that dropping a profile from an orthogonal fractional factorial will not affect the statistical properties of the design, as all profiles are statistically independent of each other. Profile 16 was dropped and the remaining 24 profiles used in the experiment.

**Table 4.2 Attribute Profiles Designed for Use in Choice Experiment**

| Profile | Landscape | Wildlife | Air Pollution | Employment | Price |
|---|---|---|---|---|---|
| 1 | Low | No Impact | Slight Increase | 1 to 3 | 16 |
| 2 | Low | No Impact | None | 20 to 25 | 45 |
| 3 | High | Slight Harm | None | 8 to 12 | 16 |
| 4 | Moderate | No Impact | None | 8 to 12 | 0 |
| 5 | High | Slight Improvement | None | 1 to 3 | 7 |
| 6 | Low | Slight Improvement | Slight Increase | 8 to 12 | 29 |
| 7 | High | Slight Harm | Slight Increase | 1 to 3 | 45 |
| 8 | None | Slight Improvement | Slight Increase | 20 to 25 | 16 |
| 9 | None | Slight Harm | Slight Increase | 20 to 25 | 0 |
| 10 | Moderate | Slight Improvement | Slight Increase | 8 to 12 | 29 |
| 11 | None | Slight Harm | None | 1 to 3 | 29 |
| 12 | Moderate | Slight Harm | Slight Increase | 1 to 3 | 45 |
| 13 | High | No Impact | Slight Increase | 8 to 12 | 0 |
| 14 | None | No Impact | Slight Increase | 8 to 12 | 7 |
| 15 | None | Slight Improvement | None | 8 to 12 | 16 |
| 16 | High | No Impact | Slight Increase | 1 to 3 | 45 |
| 17 | High | No Impact | None | 20 to 25 | 29 |
| 18 | None | No Impact | Slight Increase | 1 to 3 | 7 |
| 19 | Low | Slight Harm | None | 8 to 12 | 7 |
| 20 | Moderate | Slight Improvement | None | 1 to 3 | 16 |
| 21 | Low | Slight Improvement | None | 1 to 3 | 0 |
| 22 | None | No Impact | None | 8 to 12 | 45 |
| 23 | Moderate | No Impact | None | 1 to 3 | 16 |
| 24 | None | No Impact | None | 1 to 3 | 29 |
| 25 | None | Slight Improvement | None | 1 to 3 | 0 |

## Creation of Choice Cards

Twenty different choice sets were thus designed and used in the questionnaire. Profiles were randomly paired together by a number draw, with partial replacement so some profiles were paired with more than one other profile. Using this method was assumed to create more total choice pairings than if just 12 pairs were created from the 24 remaining profiles. The assumption was inappropriate and may be a source of increased statistical variance and heteroscedasticity.

The 20 choice sets which were created were blocked into groups of four in a survey. Each respondent received four choice sets. Each set containing two profiles and the status quo scenario (see Figure 4.1 below). Combined groupings were alternated in the order they appeared in the survey and the order of the profiles were alternated between the first and second column within each choice set (the choice set blocks may be view in Appendix B). This was done to avoid any presentation ordering bias by respondents.

Ordering bias is when respondent's answers are influenced by the order in which information or questions presented to the person. Like all bias issues in surveying and econometrics, the data becomes suspect and answers have increased uncertainty and decreased confidence (Dillman, 2000; Arsham, 2005; Louviere, et al. 2000)

**Figure 4.1 Example Choice Set**

option example

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE<br>visual impact caused by location and/or size | HIGH | NONE | No increase in renewable energy |
|  | WILDLIFE<br>health of habitat | SLIGHT HARM | SLIGHT HARM | |
|  | *AIR POLLUTION* | NONE | NONE | Alternative climate change programs used |
|  jobs | EMPLOYMENT<br>new jobs in local community | 8-12 JOBS | 1-3 JOBS | North Sea gas fired power stations instead |
| £ | PRICE OF ELECTRICITY<br>additional rates per year | £16<br>per year | £7<br>per year | |
| | YOUR CHOICE:<br>(please tick one only) | A<br>☐ | B<br>☐ | I would not want either A or B ☐ |

**General Criteria for the Design of Survey Instruments**

The following section consists of the general guidance given by Dillman (2000), Arsham (2005), and CRS (2005) on the construction and use of surveys. All of them follow the same basic format and advise, so the author has not differentiated the information. The information on survey techniques and issues by the afore mentioned sources have been combined with the works of Mitchell and Carson (1989), Bennett and Blamey (2001), and Hensher et al., (2005), all who have written on survey techniques in the context of stated preference and choice modelling/choice experiments.

The overriding consideration in questionnaire design is to make sure your questions can accurately tell you what you want to learn. The way you order questions or how a question is phrased can change the answers received. Make sure the wording does not favour one answer choice over another.

There are two broad issues when considering question and answer choice order in a survey instrument. One is how the question and answer choice order can motivate people to complete the survey. The other issue is how the order of questions or choices can bias the survey.

Ideally, early survey questions should be easy and pleasant to answer. These kinds of questions encourage people to continue the survey. Grouping together questions on the same topic also makes the questionnaire easier to answer.

Leave difficult or sensitive questions towards the end of the survey. Doing this will make it more likely people will answer these questions. Socio-economic questions like location of household and income are examples of questions many people perceive as sensitive. If people refuse to answer these questions their responses have limited use, if the covariates are included in the analysis. This would not be the case if RPL is being used for the logit analysis.

Answer choice order can make individual questions easier or more difficult to answer. Whenever there is a logical or natural order to answer choices, use it. Present agree-disagree choices in that order. Presenting the answer as disagree-agree may seem odd and confusing to both the respondent is a source of confusion when the questionnaire is in the coding process. The same issue applies to positive to negative and excellent to poor scaling. Numeric rating scale should be ordered with higher numbers meaning more positive or stronger agreement with the answer.

Question order can bias results in two ways. The first is mentioning an issue, concept or information in one question can stimulate respondents to think of it while they answer a later question, when they might not have thought of it if it had not been previously mentioned. It may be possible to limit this problem by randomizing the order of the questions. Separating related questions with unrelated ones may also limit the likelihood of this type of bias, though neither technique will eliminate it. Both of these methods may have an adverse affect and increase task complexity for the respondent.

Question order can also bias results through habituation. This applies to a series of questions which all have the same answer choices.

As is the case in the choice experiment; respondents select "A", "B" or "Neither". Some respondents will start giving the same answer, without really considering it, after being asked a series of similar questions. Several questionnaires were returned which had the appearance of this problem. Respondents tend to given greater thought when asked the earlier questions in the series and so give more accurate answers to them. This concept is called questionnaire fatigue or response fatigue.

A third way to reduce habituation is to change the "positive" answer. This applies mainly to level-of-agreement questions. It may be possible to word some statements such that a high level of agreement means satisfaction and other statements such that a high level of agreement means dissatisfaction. This technique forces the respondent to think more about each question. This is in direct contradiction to the previous guidance about presenting answers in a natural and non-contradictory manner. The information gained must be weighted by the potential coding and answer bias problems.

Respondents have a tendency to select the choices nearest the start of a list when reading the list on paper, as in a mail survey. Respondents also tend to select the most recent answer when hearing a list of choices read to them.

Sometimes answer choices have answers that are obvious to the respondent answering them, e.g. "What business or industry you work in?" The order in which answer choices are presented will not likely affect the answers given.

However, there are questions, particularly questions about personal preferences or questions with long answer choices, i.e. choice experiments, which present an idea or opinion, in which the answer choice order has greater likelihood of biasing which choice is selected.

The questionnaire needs to be as short as possible. The perception of a long time consuming survey will decrease the likelihood of a respondent even starting. And a long questionnaire is more likely to lead to response fatigue, resulting in incomplete surveys or incorrect answers. Generally, do not include a question if it is not necessary. While conducting field research is expensive, and a desire to collect all information which may be relevant is desirable, it must be limited to a level which provides accurate information.

Introduce the survey with a title which informs the respondent of the survey's objective, e.g. *IMPACTS FROM* RENEWABLE ENERGY DEVELOPMEMT IN SCOTLAND: *A SURVEY OF PEOPLE'S VIEWS* AUTUMN 2003.

Include a short introduction which states who is conducting the survey and the reasons why. Indicating that the research is being conducted for either academic or charitable organizations may increase cooperation from respondents.

A cover letter should be included in all mail surveys. A good cover letter will increase the response rate.

The use of incentives may also increase the response rate. Describe how to return the questionnaire. Include the name and telephone number of someone the respondent can call if they have any questions. Include instructions on how to complete the survey itself.

### Design of Survey Instrument

The survey instrument (questionnaire) consisted of a cover letter and the questionnaire. The questionnaire has five sections: an introduction; description of the attributes; explanation of the choice experiment, presentation of the 4 choice sets (one choice block); and a final page where socio-demographic information was collected, as well as a place for the respondent to given any additional comments or feedback on the questionnaire or topic of study. The complete survey may be seen in Appendix A. Each section is briefly described below.

i) A cover letter informed the respondent that their household had been selected to participate in a national survey of people's views on renewable energy deployment in Scotland. The research was academic in nature and being carried out by the University of Glasgow. Further more the recipient was assured confidentiality of all communications, and informed of a cash incentive for participating.

ii) The questionnaire started by presenting a simplified context of renewable energy development in Scotland. The national commitment by the United Kingdom to reduce production of greenhouse gases was explained. Survey participants were told that the survey was not concerned with any specific type of renewables technology, but with the impacts that could result from development of any renewable energy resource.

iii) The five attributes discussed earlier were described, with examples being given to clarify each type of impact.

iv) An example choice set was presented and the recipient was instructed in how the read and compare the three profiles and indicate their preference.

v) Choice sets were then presented and the survey participant was requested to indicate their preference. Each set contained three options. Plans A and B were possible renewable energy projects, each with different attribute levels. A third option of choosing neither was given. This 'neither' option, commonly called the opt-out or status quo option, stated that there would be no increase in renewable energy, that alternative programs would be implemented to avoid climate change, and that North Sea natural gas usage would be expanded to provided for future electricity generation.

vi) The final page of the questionnaire was concerned with collecting standard socio-economic information about the participant. Information was requested about location of household, number of children, employment in the energy sector, membership in a conservation group, age, household income, education attainment, and amount of last electric bill.

### Survey Pilot Test

The questionnaire and accompanying cover letter were than submitted to a small pre-test with regard to their clarity and usefulness of the information contained. Feedback from this process lead to a revised and shortened version of the cover letter, clarification of some terminology and changes in how the socio-economic information was requested in the questionnaire.

### General Criteria for Sample Selection

There are two main concerns in deciding whom to survey. The first is deciding what kind of people to survey. These people are called the target population or sample frame. Correctly determining the target population is critical. If the correct target population is not surveyed the analytic findings will be of limited value. If the sample is incorrectly drawn from the population it is said to be "biased". Types of bias are described at the end of this section.

Determining the sample size is the second main concern when conducting a survey. Statisticians have proven that a small, representative sample will reflect the group from which it is drawn (Greene, 2003). The larger the sample, the more precision and confidence can exist that the target population is being represented. However, the rate of improvement in precision decreases as the sample size increases. For example, increasing a sample from 250 to 1,000 only doubles the precision of the estimates. Decisions about sample size are commonly based on factors such as: time available, budget and necessary degree of precision. The main objective is to obtain both a desirable accuracy and a desirable confidence level with minimum cost.

To calculate the desired size of sample population certain statistical terms need to be defined.

- Population Proportion: The percentage of people in the population who will respond a certain way for a given issue. This is an actual percentage which we would know if we were able to include everyone in a given population in a survey. We are attempting to estimate the population proportion by sampling a smaller group of people.
- Sample Size: The number of people in the survey.
- Margin of Error, or Precision: The "plus or minus" amount, or percentage in the case of estimating proportions.
- Confidence Level: The degree to which you are certain that the result, or estimate, you obtain from the study includes the true population percentage, when the precision is taken into account. Typical confidence levels are 80%, 90%, and 95%, although any confidence level can be used.

(Business Research Lab, 2005)

By assigning values to any three of these four variables, it is possible to determine the unknown variable which in this instance is sample size.

The population proportion variable is assigned a value of 0.5. This value is the proportion which will give the greatest confidence in having the correct sample size. As no information exists to estimate which of the profiles or attributes will be chosen in the survey choice sets it is assumed to be the greatest variance, the value 0.5. The margin of error variable is assigned a value of +/- 5%. This is the desirable standard of precision used in stated preference analysis. Confidence level is assigned a value of 95%, which is the common valued used by econometric analysis (Greene, 2003; Louviere, 2000). One final datum is required; the total population size. In this research the adult population of Scotland was used, 4,000,000 persons[11].

Once these parameters are determined, two methods can be used to determine the necessary sample size. The first is to use statistical tables which list the required size. The second is to use statistical software.

**Quotas and Stratified Sampling**

A quota is a sample size for a sub-group. It is sometimes useful to establish quotas to ensure that your sample accurately reflects relevant sub-groups in your target population. For example, men and women have somewhat different opinions in many areas. If you want your survey to accurately reflect the general population's opinions, you will want to ensure that the percentage of men and women in your sample reflect their percentages of the general population.

Stratified sampling is a random sampling technique (Ryerson, 2005). The whole population is first placed into mutually exclusive

[11] 72% of the Scottish population was age of 20 or greater in 2001. Population in 2001 was 5.06 million people. National Statistics 2005

subgroups or strata and then units are randomly selected from each stratum. The segments are based on some predetermined criteria such as geographic location, size or demographic characteristic. It is important that the segments be as heterogeneous as possible. In simple random sampling, there is no assurance that a sufficient number of any single sub-group would actually be included in the sample.

Proportionate stratified sampling is an additional attempt to assure proportional representation of sub-populations of interest. For example, if one-quarter of the target population were women, the survey would attempt to maintain that same ratio in the sampling process.

Disproportionate sampling is only undertaken if a particular strata is very important to the research project but occurs in too small a percentage to allow for meaningful analysis unless is representation is artificially boosted. In this technique you over sample and then weight your data to re-establish the proportions. Extending this from the previous example, assume there is only enough budget to survey 300 people, but inclusion of at least 100 women is required to have a sufficient number for further analysis. This means that you over sample for women ratio of 1.33:1. Thus, the final data would need to be weighted for each of the women respondents to end up with the proper proportions (Ryerson, 2005).

## Types of Sampling Bias

There are several types of sampling bias:

Population choice bias - when the researcher misidentifies the population whose values the study is intended to obtain.

Sampling frame bias – the frame may be a list or a method of generating a list of potential respondent. If the population and the sapling frame diverge sampling frame bias can occur. For mail surveys, Mitchell and Carson (1989) recognise a problem with mailing surveys is to acquire an up-to-date address list of every potential sample group member of interest because of the frequency with which people change residences. They go on to state, "There are likely to be fewer problems of this kind where the appropriate sampling frame consists of a current list of addresses held by a government agency – a list of the holders of fishing or hunting licenses, for example."

Non-response bias – there are two types of non-response bias. Unit non-response (Kalton, 1983) is where a person or household fails to respond to a questionnaire. Item non-response a respondent answers some or most of the questions on a survey but fails to answer a particular questions of interest. Income is a common item non-response item.

Sample non-responses bias – the response rates between sub-groups in the sample group are different such as education level and income level differences, these categories of people tend to also hold different values for public goods.

Generally these types of non-response will be random and occur in an independent manner from one individual or household to another.

**Sample Selection for Choice Experiment**

The parameters selected for this choice experiment are as follows:

- Population Proportion: 0.50.

  This is the most conservative value that can be used in determining sample size. Maximises required sample population size. Given that no useable a priori knowledge exists which on the people's preferences being investigated this is the appropriate value.

- Margin of Error, or Precision: +/- 5%. This is the standard precision used in econometric research and in stated preference research (Hensher et al., 2005).
- Confidence Level: 95%. This is the standard used in econometric research and in stated preference research (Hensher et al., 2005).
- Target Population: 4,000,000. This is the size of the Scottish population over the age of 20. It was determined that only the preferences of the adult population were desired.

To meet or accede these statistical parameters a sample size large enough to attain 384 respondents is required. Statistical software available on the internet[12] was used to calculate this quantity. It was confirmed by using SPSS statistical software also.

If the survey was conducted through interviews, the required sample size would also be the number of interviews. However this

[12] Sample Size Calculator,
http://www.gifted.uconn.edu/siegle/research/Samples/samplecalculator.htm

research is being carried out with a mail survey. So the sample size needs to be large enough to attain 384 respondents.

**General Criteria for a Mail Surveys**

**Advantages**

- Mail surveys are among the least expensive.
- This is the only kind of survey you can do if you have the names and addresses of the target population, but not their telephone numbers.
- The questionnaire can include pictures - something that is not possible over the phone.
- Mail surveys allow the respondent to answer at their leisure, rather than at the often inconvenient moment they are contacted for a phone or personal interview. For this reason, they are not considered as intrusive as other kinds of interviews.

**Disadvantages**

- Time! Mail surveys take longer than other kinds. You will need to wait several weeks after mailing out questionnaires before you can be sure that you have gotten most of the responses.
- In populations of lower educational and literacy levels, response rates to mail surveys are often too small to be useful. This, in effect, eliminates many immigrant populations that form substantial markets in many areas. Even in well-educated populations, response rates vary from as low as 3% up to 90%. As a rule of thumb, the best response levels are achieved from highly-

educated people and people with a particular interest in the subject (which, depending on your target population, could lead to a biased sample).

One way of improving response rates to mail surveys is to mail a postcard telling your sample to watch for a questionnaire in the next week or two. Another is to follow up a questionnaire mailing after a couple of weeks with a card asking people to return the questionnaire. The downside is that this doubles or triples your mailing cost. If you have purchased a mailing list from a supplier, you may also have to pay a second (and third) use fee - you often cannot buy the list once and re-use it.

Another way to increase responses to mail surveys is to use an incentive. One possibility is to send a dollar bill (or more) along with the survey (or offer to donate the dollar to a charity specified by the respondent). If you do so, be sure to say that the dollar is a way of saying "thanks," rather than payment for their time. Many people will consider their time worth more than a dollar. Another possibility is to include the people who return completed surveys in a drawing for a prize. A third is to offer a copy of the (non-confidential) result highlights to those who complete the questionnaire. Any of these techniques will increase the response rates.

Remember that if you want a sample of 1,000 people, and you estimate a 10% response level, you need to mail 10,000 questionnaires. You may want to check with your local post office about bulk mail rates - you can save on postage using this mailing method. However, most researchers do not use bulk mail, because many people associate "bulk" with "junk" and will throw it out without opening the envelope, lowering your response rate. Also bulk mail moves slowly, increasing the time needed to complete your project.

**Mail Survey for Choice Experiment**

A mail survey was used due to a constraint imposed by project funding. This is not an uncommon occurrence in stated preference research (Gordon et al., 2001). A researcher must try to include the maximum number of respondents that can be reached. If the number of respondents is below the minimum sample size required, it becomes even more important to test if the sample is representative of the target population.

NOTE: Even if the required sample size is met, it must be tested for representing the target population. Attaining the necessary sample size is not sufficient in itself to assure any statistically requirements.

The sampling frame for this project was the Scottish general public. Our sample population was randomly selected from the list of registered voters in eight council districts of Scotland. The districts are Aberdeenshire, Highlands and Islands, Western Isles, Edinburgh, Glasgow, Stirling, Borders, and Dumfries and Galloway. Approximately 250 names were from Glasgow and Edinburgh, 80 from Aberdeenshire, and 30-45 names from each of the other districts.

The areas were selected as a disproportionate stratified sample to increase the likelihood of capturing both the overall preferences of

Scottish adults, as well as the preferences of rural populations which would be most affected by the deployment of renewable energy projects.

547 names were selected and mailed survey packages with a cover letter during the first week of September 2003.

### Use of Cash Incentive

As an incentive to participate a £20 prize draw was offered to those who completed and returned the survey. One in 100 of the respondents would be randomly selected to receive the cash. There is some debate on the effectiveness of offering cash incentives to increase participation rates from a mail survey (Church, 1993). The particular method used in this research is not believed to improve the response rate in any statistically measurable manner. However, it has been demonstrated that no harm to the response rate. Given this situation it was decided to offer the incentive, as any marginal increase in responses would be helpful to the research. Slightly over 200 responses were received. £20 was sent by check to two randomly selected respondents. Approximately one-half of the respondents registered in the survey to participate in the incentive draw. There was no method included in the survey instrument of identifying respondents if they did not given their name and address. See page two of the survey, Appendix A.

## Response Rates and Respondent Characteristics

### Response rate

Three weeks after the survey was mailed out, a follow-up postcard was mailed to encourage the completion and return of the survey. By October 2003, 219 households had returned surveys, a 43% response rate after undeliverable letters are considered. 211 surveys were received in time to be part of the sample set. 8 surveys were returned too late to be included. 287 households did not respond. This response rate is acceptable, and comparable to other studies, (Ek, 2002; Hanley, et al., 2001) that had response rates ranging from 44% to 56%, for a survey mailed to the general population. Mail surveys tend to have the lower response rates than telephone or face-to-face interviews (Bateman, et al., 2002).

### Descriptive Statistics of Respondents <u>Tables 4.3a to Table 4.3f</u>

**Table 4.3a Age Distribution (by survey categories)**

| | <25 | 25-40 | 41-54 | 55-65 | >65 | No response | Total |
|---|---|---|---|---|---|---|---|
| Number Respondents | 10 | 56 | 56 | 35 | 49 | 5 | 211 |
| % Respondents | 4.7% | 26.5% | 26.5% | 16.6% | 23.2% | 2.4% | 100.0% |

**Table 4.3b Location of Household (by survey categories)**

| | City | Town | Village or Countryside | No response | Total |
|---|---|---|---|---|---|
| Number of Respondents | 88 | 33 | 86 | 4 | 211 |
| % Respondents | 42.0% | 16.0% | 41.0% | 2.0% | 100% |

**Table 4.3c Gross Household Income Distribution (by survey categories)**

| Income Bracket | Number of Respondents | % Respondents |
|---|---|---|
| £0 - < £10,000 | 29 | 13.7% |
| £10,000 - £15,999 | 40 | 19.0% |
| £16,000 - £20,999 | 19 | 9.0% |
| £21,000 - £25,999 | 21 | 10.0% |
| £26,000 - £30,999 | 13 | 6.2% |
| £31,999 - £35,999 | 20 | 9.5% |
| £36,000 - £40,999 | 12 | 5.7% |
| £41,000 - £45,999 | 5 | 2.4% |
| £46,000 - £50,999 | 5 | 2.4% |
| £51,000 - £55,999 | 6 | 2.8% |
| £56,000 - £60,999 | 2 | 0.9% |
| £61,000 - £65,999 | 4 | 1.9% |
| £66,000 - £70,999 | 4 | 1.9% |
| £71,000 - £75,999 | 0 | 0.0% |
| £76,000 - £79,999 | 1 | 0.5% |
| £80,000 > | 5 | 2.4% |
| No response | 25 | 11.8% |
| Total | 211 | 100.0% |

**Table 4.3d Membership in Conservation Group(s)**

| | Number of Respondents | % Respondents |
|---|---|---|
| Member | 16 | 8.0% |
| Non-remembers | 178 | 84.0% |
| No response | 17 | 8.0% |
| Total | 211 | 100.0% |

**Table 4.3e Employed in Energy Sector**

| | Number of Respondents | % Respondents |
|---|---|---|
| Employed in sector | 18 | 9.0% |
| Not employed in sector | 187 | 89.0% |
| No response | 6 | 3.0% |
| Total | 211 | 100.0% |

**Table4.3f Child(ren) (living at home or away)**

| | Number of Respondents | % Respondents |
|---|---|---|
| Respondent with child(ren) | 145 | 69.0% |
| Respondent without child(ren) | 62 | 29.0% |
| No response | 4 | 2.0% |
| Total | 211 | 100.0% |

**Testing Sample Group for Bias and Representation of Target Population**

Any mail out survey has the risk of self-selection bias. Self-selection bias, also called sample selection bias, occurs when the non-response from the sample population is not random, but rather individuals who do not respond are representative of a group who hold different values for a good from those who do respond. The inverse can also be true, that individuals who hold different values for a good select themselves into the sample in a disproportionate manner. Both types of self selection bias can occur more easily with mail out surveys than telephone, person-to-person interviews and internet surveys.

Comparing the socio-economic information collected on the 211 respondents who are included in the choice experiment analysis to the statistical profile of the Scottish population is one test for such a bias.

Two statistical tests are used to determine if the sample is an acceptable representation of the whole population. The first is the proportional chi-square test (also known as the Pearson Chi-square). The second is the student's t-statistic.

The Pearson Chi-square is the most common test for significance of a relationship between categorical variables (Stat Soft, 2003). The measure is based on statistical theory that the expected frequencies in a two-way table can computed, i.e. frequencies that would be expect if no relationship between the variables existed. For example, suppose 100 rural respondents and 100 urban respondents are asked to choose between two renewable energy profiles. If there is no relationship between preference and residence location, then it would expected to find an equal number of choices of each profile for each location. The Chi-square test statistic increases in significance as the respondent's answers deviate further from the expected pattern.

The value of the Chi-square and its significance level depends on the overall number of observations and the number of cells in the table. Relatively small deviations of the relative frequencies across cells from the expected pattern will prove significant if the number of observations is large (Stat Soft, 2003).

The only assumption underlying the use of the Chi-square (other than random selection of the sample) is that the expected frequencies are not very small. The reason for this is that, actually, the Chi-square inherently tests the underlying probabilities in each cell; and when the expected cell frequencies fall, for example, below 5%, those probabilities cannot be estimated with sufficient precision (Everitt, 1977; Hays, 1988; and Kendall and Stuart 1979).

Standard procedures for testing sample statistics are to identify a null hypothesis and an alternative hypothesis (Hill et al., 2001). In the case of the proportional Chi-square test the null hypothesis is that the sample population is equal to the national population. The null hypothesis must not be accepted for sample bias to be shown.

In the sample, respondent's income and location of residence are different from the national proportions, at the 10% level. The null hypothesis is rejected. The sample does not represent the whole population.

Our sample is proportionally weighted to lower income levels than the national proportions, and the sample is more rural than the national proportions. These two descriptors are in fact correlated with each other (SPIU, 2005). Rejection of the null hypothesis means that the estimated coefficients and the calculated WTP values may not be statistically valid representations of the whole Scottish population.

The second test is the student's t-statistic test. The mean and standard error is calculated for the sample population for each characteristic, location and income. A confidence interval is configured around the mean. The null hypothesis state that the sample represents the whole population is accepted if the population mean lays within the interval. For characteristics, location and income, the null hypothesis was not accepted. The t-test is of limited validity in this context, as the sample and the population are not normally distributed. However, it is an acceptable secondary support of the prior Chi-square test.

**Data Analysis**

To model the information collected from the questionnaire, each choice set has three lines of code that combines the attribute levels, ASCs and socio-economic variables (Bennett and Blamey, 2001). The data matrix appeared in the form:

Alternative Plan A: $V_a = ASC_a + \beta_{attributes}X + \beta_{soci\text{-}econ}Y$

Alternative Plan B: $V_b = ASC_b + \beta_{attributes}X + \beta_{soci\text{-}econ}Y$

No Renewables Option: $V_n = \beta_{attributes}X + \beta_{soci\text{-}econ}Y$
(The neither/opt-out plan)

where **V** is the conditional indirect utility, $ASC_{a,b}$ are the alternative specific constants for each choice plan, $\beta_{attributes}$ is a vector of coefficients associated with the attributes **X** and levels, and $\beta_{socio\text{-}econ}$ is a vector of coefficients associated with the socio-economics descriptors **Y** of the respondents.

NLOGIT 3.0/LIMDEP 8.0 econometric software was used to estimate the MNL model. Attributes were effect coded, rather than being coded using dummy variables, as this will provide estimates that are uncorrelated to the intercept of the model (Louviere, et al., 2000). Effect coding means that at least one level of each attribute is not included as an identified variable: thus a 3-level attribute generates two variables. The excluded level is coded as negative one. The attributes levels chosen for exclusion were the ones hypothesised to have the most negative effect on environmental amenities. Therefore, the estimated coefficients for each of the remaining levels indicate the value respondents placed on the change from the lowest valued (omitted) level to the level of greater utility. The omitted levels were: High Landscape Impact, Slight Wildlife Harm, and Slight Increase in Air Pollution. The effect of these omitted levels on utility is given by the negative of the sum of the coefficients on all the included levels.

## Model Estimation

### Multinomial Logit Model

Results for all 211 respondents from the MNL model are shown in Table 4.4. The "simple" model shows results when only the choice experiment attributes are included in the regression. The coefficients are interpreted as the parameters of the indirect utility function, although the fact that they are confounded with a scale parameter means that one cannot directly interpret their numerical value

The MNL models are shown in Table 4.4. The "Simple MNL" model consists of a regression which includes only the key attributes from the choice experiment. The "MNL Model with covariates" consists of the key attributes and three covariates: household income, education of respondent, and age of respondent.

The coefficients are interpreted as the parameters of the indirect utility function, although they are in fact confounded with a scale parameter which means that it is not possible to directly interpret the numerical values. The scale parameter can be eliminated by cancellation[13] when calculating implicit prices, marginal rates of substitution between attributes, or welfare measures.

[13] If a common factor exists in both the denominator and numerator of a fraction, the factor can be eliminated in simplification of the expression (Swift and Piff, 2005).

The sign on each coefficient indicates the influence that each attribute has on choice probabilities. All attribute coefficients, in both models, have the expected values. The values of all but the price attribute are positive, as consumer preference theory predicts (Mas-Colell,1995), since these attributes are expressed in the analysis to show an increase in environmental quality, which is expected to result in increased utility by respondents. Price is found to be a negative value and therefore is also in accord with standard economic theory which states that an increase in price of a normal good should decreases consumer utility (Mas-Colell, 1995).

All of the environmental attributes are significant determinants of utility at some level: changes in air pollution, landscape effects and wildlife effects. However, employment creation is found to be non-significant as an attribute.

A series of socio-economic variables (respondent descriptive) were proposed for inclusion in an "MNL with covariates" model based on standard consumer theory and stated preference studies. The student t-test and log likelihood tests were used to determine acceptance or rejection of each socio-economic variable. The rejected descriptive variables were: does the respondent have children; employment in the energy sector; membership in a conservation group; monetary amount of last electric bill; age (five categories); and education (three categories).

The remaining covariates used in the "expanded" model show either statistical significance; or are included on substantial theoretical and social policy grounds. Education and age are in the former class, while income is the latter case. (Dodgson et al., 1990; Batley et al., 2001; EK, 2005)

**Table 4.4 Multinomial Logit Model**

| Variable Descriptor | Coefficients : MNL with Covariates | Standard Error | Coefficients : MNL | Standard Error |
|---|---|---|---|---|
| Landscape change: moderate | 0.2968 ** | 0.1551 | 0.2151 | 0.1396 |
| Landscape change: low | 0.1352 | 0.2057 | 0.1561 | 0.1857 |
| Landscape change: none | 0.4222 * | 0.1064 | 0.3898 * | 0.0986 |
| Wildlife: no impact | 0.2170 * | 0.1061 | 0.2720 * | 0.0974 |
| Wildlife: slight improvement | 0.6251 * | 0.1283 | 0.4989 * | 0.1157 |
| Air Pollution: none | 0.7389 * | 0.0658 | 0.7098 * | 0.0589 |
| Jobs created | 0.0169 | 0.0120 | 0.0111 | 0.0110 |
| Price | -0.0518 * | 0.0065 | -0.0490 * | 0.0059 |
| Alternative Specific Constant - A | 3.2875 * | 0.6004 | 2.9528 * | 0.4605 |
| Alternative Specific Constant - B | 3.0968 * | 0.5990 | 2.7891 * | 0.4620 |
| [a]Income - A | -0.0047 | 0.0101 | | |
| [a]Income - B | -0.0060 | 0.0101 | | |
| [b]Education - A | 1.0505 * | 0.3810 | | |
| [b]Education – B | 0.9037 * | 0.3832 | | |
| [c]Age - A | -0.7750 ** | 0.3619 | | |
| [c]Age - B | -0.5701 | 0.3653 | | |
| Number of Observations | 739 | | 836 | |
| Log-likelihood | -435.20 | | -509.79 | |
| Psuedo-$R^2$ | 0.4581 | | 0.4416 | |

* Indicates significance at !% level; ** Indicates significant at 5% level
a Respondent's household income level
b Respondent's education level ( Higher Education = 1; General Education = 0)
c Respondent's age (Less than 41 years age = 1; More than or equal to 41 years age = 0)

Scotland has an on going social policy debate on the effect renewable energy will have household energy prices and low income households which may be driven into fuel poverty[14] (EAS, 2004). Fuel-poor households in Scotland numbered 262,000 in 2002, 12% of all households. The number of households in fuel poverty is down from 738,000 (35% of households) in 1996 (EAS, 2004).

A likelihood ratio test was used to compare the "simple" and "with covariates" models, to determine if the models were significantly difference from each other. The likelihood ratio test rejected the null hypothesis[15]; therefore the models are difference from each other.

Several statistical tests were used to compare these two models. Implicit prices[16] derived from the two models were compared and were not found to be statistically different. The student's t-test was used for comparison of the respective implicit prices. This result is also easily confirmed by a simple visual examination and recognition of the large overlap of confidence intervals (95% level) of both models implicit prices.

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[14] The Scottish Executive has adopted the definition of fuel poverty used in the UK Fuel Poverty Strategy; however it is more specific in certain areas, including the definition of a 'satisfactory heating regime' which uses the levels recommended by the World Health Organisation. For elderly and infirm households, this is 23 C in the living room and 18 C in other rooms, to be achieved for 16 hours in every 24. For other households, this is 21 C in the living room and 18 C in other rooms for a period of nine hours in every 24 (or 16 in 24 over the weekend), with two being in the morning and seven hours in the evening. 'Household income' would be defined as income before housing costs, to mirror the definition used in the UK Households Below Average Income Statistics (EAS, 2004).

[15] The null hypothesis states the parameter values of the two models are equal at the 95% significance level.

[16] Implicit prices ("part-worths") are interpreted as the incremental willingness-to-pay through an increase in electricity charges per annum per household for a change in any of the attributes.

The standard errors and confidence intervals for these non-linear functions were calculated by LIMDEP 8.0 using the delta method.

The adjusted McFadden Pseudo-$R^2$ is also improved with the addition of the covariates. Louviere, et al., (2000) states that a McFadden statistic in the 0.20 to 0.30 range is comparable to an ordinary least square (OLS) adjusted-$R^2$ of 0.70 to 0.90. Therefore, the MNL model with covariates is deemed the superior model.

One final test was conducted on both of models, the Independence from Irrelevant Alternatives test. See earlier discussion of the IIA requirement in this chapter. Both models failed the IIA test. Regardless which plan was excluded for the test, Plan A or Plan B, the MNL models were found to violate this essential assumption. <u>**Neither MNL models can be accepted.**</u>

**Random Parameter Logit Model**

When heterogeneity is present, it is appropriate to specify a choice model which accounts for this heterogeneity[17]. A "random parameter logit" model was therefore used (Train, 1998). The RPL model has been described in an earlier section, Economic Theory and Econometric Models. Given that income and location of residence were positively identified as a source of heterogeneity the sample was segregated into sub-groups for further investigation.

[17] The Multinomial Logit Model assumes that people tastes are homogeneous throughout the population. If it is not true, the resulting parameter estimates are biased and can no longer be used for preference and welfare estimates (Hensher, 2001)

Two sub-groups were created to test for statistical significance due to household income levels. One group had income below £16,000 per annum, while the other had income of £16,000 or greater per annum. RPL models were estimated for both sub-groups and a likelihood ratio test conducted. A likelihood ratio test is used to verify if the two groups were statistically different, or if they could be pooled together (pooled together is the null hypothesis). If the groups are structurally different, then the summed log-likelihood values will be greater than the log-likelihood value of the combined groups (Greene, 2003). The null hypothesis is accepted; therefore separating the sample into two groups will not increase explanatory power nor reduce heterogeneity.

The same test was completed for the location of residence characteristic. By segregating the sample into two groups based on location of residence either rural or urban. This characteristic was self-declared by respondents in the socio-demographic portion of the questionnaire. There were three possible options; residing in a city, a small town, or a village/the country. The null hypothesis that the groups should be pooled together was not accepted. Location is statistically significant in estimating the preferences of the sample population and is therefore a source of heterogeneity. Estimates of preferences are improved by separating the sample into two groups.

The estimated coefficients derived from the random parameter logit model are shown below (Table 4.5).

Table 4.5, the second column describes the estimated coefficients of the entire sample population, whilst columns 3 and 4 show the estimated coefficients of the sub-sample populations: urban and rural residents. When interpreting the coefficients, it must be remembered that the coefficients describe the contribution of the attributes to choice probabilities: positive coefficients reveal an increase in the choice probability, negative coefficients a decrease. Qualitative variables were coded using effect codes, so that the value of the omitted level is equal to the negative of the sum of the included levels.

**Table 4.5 Random Parameter Logit Model**

| Variables | Total | Urban dwellers | Rural dwellers |
|---|---|---|---|
| *Mean* | | | |
| Constant | 3.406 * | 3.131 * | 4.878 * |
| Landscape change: moderate | 0.186 | -0.133 | 0.587 *** |
| Landscape change: low | 0.225 | 0.698 *** | -0.436 |
| Landscape change: none | 0.470 * | 0.492 ** | 0.537 ** |
| Wildlife: no impact | 0.331 ** | 0.313 | 0.467 *** |
| Wildlife: slight improvement | 0.735 * | 0.795 * | 0.961 * |
| Air Pollution: none | 0.929 * | 0.893 * | 1.092 * |
| Jobs created | 0.013 | -0.011 | 0.068 * |
| Price | -0.067 * | -0.086 * | -0.063 * |
| Age[a] | 1.186 ** | 1.677 | 1.048 |
| Education[b] | 1.312 ** | 2.339 * | 0.742 |
| Income[c] | -0.015 | -0.032 | 0.004 |
| *Standard Deviation* | | | |
| Landscape change: moderate | 0.460 | 0.748 ** | 0.649 *** |
| Landscape change: low | 0.972 ** | 1.183 ** | 1.387 ** |
| Landscape change: none | 0.796 * | 0.877 * | 0.380 |
| Wildlife: no impact | 0.569 ** | 0.373 | 0.853 *** |
| Wildlife: slight improvement | 0.295 | 0.275 | 0.186 |
| Air Pollution: none | 0.361 * | 0.612 * | 0.199 |
| Jobs created | 0.031 * | 0.037 ** | 0.010 |
| Number of observations | 828 | 476 | 352 |
| Log likelihood at constant | - 700.23 | - 392.79 | - 306.24 |
| Log likelihood at convergence | - 470.30 | - 263.69 | - 190.12 |
| Likelihood Ratio | 459.86 | 258.20 | 232.24 |
| Pseudo $R^2$ | .473 | .487 | .497 |

Clarification

* Indicates significance at 1 % level, ** Indicates significance at 5 % level,
*** Indicates significance at 10 % level.
[a] Respondents' age (Less than 41: 1; More than or equal to 41: 0)
[b] Respondents' education (High Education: 1; General education: 0)
[c] Respondents' income

Overall, each model is highly significant and shows a very good fit when comparing the log likelihood values at zero and at convergence[18]. The signs of all coefficients are consistent with a priori expectations. Starting with the "total sample" model the high significance and positive value of the constant indicates, everything else equal, respondents support renewable energy expansion. The constant is interpreted as the effect of systematic factors not included as attributes. The landscape change coefficients specify that only a change from high impact to the absence of any impacts significantly affects choice. The effect of renewable energy projects which may have on wildlife is very important, and projects that may cause slight harm to wildlife are less likely to be chosen. On the other side, projects that produce a slight improvement on wildlife are preferred to ones that have no impact on it. This is demonstrated by the coefficient for "wildlife: slight improvement" being larger than the coefficient for "wildlife: no impact". People care a lot about the effect projects can have on air pollution. Interestingly, the jobs attribute is not a significant determinant of choice: that is, generally there are other more important issues than jobs which motivate people to support renewable energy projects. The negative sign on the price attribute reveals the negative effect that people perceive from electricity price increases. The higher the cost associated with any alternative, the lower the probability that alternative has of being. This is consistent with standard consumer theory.

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[18] Simulations conducted by Domenich and McFadden (1975) compare values of pseudo-$R^2$ between 0.2-0.4 to values between 0.7-0.9 of the $R^2$ of the ordinary least squares linear regressions.

The socio-economic variables which were included in the model show that both age and education influence choices. People who are younger than 41 years and/or have earned a higher education degree are more likely to support renewable energy projects. Income was not a significant determinant of choice. This lack of significance is possibly the result of the proposed increased in electricity prices in the experiment still being affordable to all respondents.

Most coefficients' standard deviations are significant. This is a clear indication that respondent's preferences are indeed heterogeneous. Heterogeneity arises from different values being held by respondents about the potential impacts of renewable energy projects. Considering landscape impacts, for example, there are individuals who firmly believe that wind mills are "beautiful and gracefully", whilst others believe that they destroy the quality of the landscape: our model results provide evidence of this variation in preferences.

It is important to note the size, magnitude and statistically significance of the ASC for each of the three models. The ASC captures the unexplained endogenous values held by the respondents; the ASCs within each model have coefficients which range from three to ten times larger than the attribute or covariate coefficients. Relative to the other explanatory coefficients, these ASCs can be interpreted to show the existence of a strong and substantial preference for all renewable energy profiles over the status quo. This finding is supported by the public opinion surveys which were described in the prior chapter.

### Comparing Urban and Rural responses

The urban and rural sub-sample models show preferences do differ between the two groups. Urban residents prefer projects that have low or no landscape impact (in spite of the existence of heterogeneity in this attribute), do not harm wildlife and do not generate air pollution. Creation of new permanent jobs is not a concern for urban respondents. Rural residents can be inferred to have greater support for renewable energy projects by having more significant coefficients which are positive in value and a smaller negative coefficient on the price attribute. Interestingly, rural respondents are very influenced by projects that create new permanent jobs, unlike the urban sample. This may reflect a perception that renewable energy projects will be constructed and maintained in rural areas.

### Implicit Prices

The implicit prices of the attributes support the interpretation of the model coefficients. Table 4.6 lists the implicit prices estimated for the three models, with their 95% confidence intervals[19]. For the landscape attribute a moderate or a low change in landscape quality does not have a positive willingness-to-pay in all models, since the confidence interval of the implicit prices overlaps zero. The full sample and the urban sample have a positive willingness-to-pay for projects that do not cause any landscape change; whilst the rural sample has implicit prices for changes in the landscape attribute that are not statistically different from zero. The

[19] The Krisky and Robb (1986) bootstrapping procedure was used for the confidence intervals estimation.

wildlife attribute has positive values associated with it, and in particular a "slight" improvement in wildlife has a willingness-to-pay value of £10.95. Respondents are also willing to pay an average of £13.84 for projects that do not increase air pollution. Only the rural respondents have a significant and positive implicit price for the creation of new permanent jobs. In the rural sample an average respondents would be willing to give £1.08 for creation of each new permanent job. This underlines the importance rural residents place on any development plans that may increase the number of jobs locating in their areas.

**Table 4.6** **Implicit Prices**

| | Total sample Implicit Price | Urban dwellers Implicit Price | Rural dwellers Implicit Price |
|---|---|---|---|
| **Attributes** | | | |
| Landscape change: moderate | 2.77 (-2.52; 9.06) | - 1.54 (- 7.69; 5.40) | 9.38 (- 1.49; 26.56) |
| Landscape change: low | 3.36 (-4.71; 10.16) | 8.08 (-0.91; 14.79) | - 6.97 (- 27.54; 6.88) |
| Landscape change: none | 7.00* (2.73; 11.79) | 5.69* (0.88; 11.63) | 8.59 (- 0.48; 14.47) |
| Wildlife: no impact | 4.94* (0.96; 10.16) | 3.63 (-0.82; 9.13) | 7.47* (0.09; 16.59) |
| Wildlife: slight improvement | 10.95* (6.74; 14.61) | 9.19* (3.24; 14.52) | 15.35* (8.97; 23.27) |
| Air Pollution: none | 13.84* (10.78; 18.45) | 10.33* (7.24; 15.30) | 17.45* (11.97; 27.64) |
| Jobs created | 0.19 (- 0.25; 0.61) | - 0.13 (- 0.64; 0.38) | 1.08* (0.22; 2.09) |

* Statistically different from 0 at 95% confidence level

### Social Welfare Changes from New Renewable Energy Projects

From a policymaker's perspective, deriving welfare estimates is a useful aspect of choice experiments for use in benefit-cost analysis. Instead of just focusing on individual attribute values, choice experiments offer the ability to estimate the economic value of alternative projects which change the levels of some or all attributes simultaneously. To achieve this, a comparison of utility can be made between a reference project and a series of alternative projects, as long as each can be described using the attribute levels used in the experiment. The utility of any alternative project is calculated by subtracting it from the utility of the status quo project; this result is then divided by the negative of the cost coefficient to convert from utility units to money-equivalent units of measurement (Bennett and Blamey, 2001).

$$\text{Welfare Change} = -1 / b_m (V0 - V1) \qquad \textit{(Eq. 4.8)}$$

where $b_m$ is the estimated coefficient on the monetary attribute from the choice model, Vo is the value of the indirect utility associated with the reference project and V1 is the value of the indirect utility associated with any other alternative. In this context, alternative renewable energy projects can be compared to the "no increase in renewable energy source alternative" (reference case). The resulting monetary value is the welfare change that results from the particular alternative project as compared to the reference project. Four different energy project scenarios were considered:

A. Large Offshore Windmill Farm – 200 MW, 100 turbines each at 80 meters nacelle hub height, 6-10 kilometres from shore.

B. Large Onshore Windmill Farm – 160 MW, 80 turbines each at 80 meters nacelle hub height.

C. Moderate Windmill Farm – 50 MW, 30 turbines each at 60 meters nacelle hub height.

D. Biomass Power Plant – 25MW, emissions stack height up to 40 meters, portions of building up to 30 meters, fuelled by energy crops.

All of these energy project scenarios are taken from actual projects that have been constructed or are proposed and in the process of being permitted. The three wind farms are derived from information from the British Wind Energy Association (BWEA, 2003). The biomass power plant description was taken from the Peninsula Power Project, a biomass power plant proposed for the Devon region of England (Peninsula Power, 2004).

There is some concern about the status quo or opt-out profile which was developed and used in this experiment. A question exists about the sufficiency of the profile to inform participants of the attributes from continued generation fuelled by natural gas from Peterhead Power Station. If there was insignificant information than the social welfare values derived in this section should be treated with scepticism (Bennett and Blamey, 2001). However, the implicit prices estimated from this research are not affected.

**Table 4.7** Welfare Changes from New Renewable Energy Projects

| *Scenario:* | *Base Case* Fossil Fuel power station expansion | *A* Large Offshore Wind farm | *B* Large Onshore Wind farm | *C* Small Onshore Wind farm | *D* Biomass Power Plant |
|---|---|---|---|---|---|
| Attribute Levels: | | | | | |
| *Landscape* | Low | None | High | Moderate | Moderate |
| *Wildlife* | None | None | None | None | Improve |
| *Air Pollution* | Increase | None | None | None | Increase |
| *Employment* | +2 | +5 | +4 | +1 | +70 |
| Welfare Change (£/hsld/yr.): **Total sample** | | 31.88 (19.02, 48.29) | 11.57 (-2.67, 29.63) | 26.91 (12.98, 44.52) | 18.14 (-12.97, 52.80) |
| Welfare Change (£/hsld/yr.): **Urban sample** | | 17.87 (5.74, 37.57) | 0.08 (-15.40, 21.65) | 11.17 (-0.59, 30.57) | 12.99 (-47.72, 20.73) |
| Welfare Change (£/hsld/yr.): **Rural sample** | | 53.71 (29.90, 91.82) | 33.04 (5.70, 70.80) | 50.16 (24.30, 96.54) | 97.95 (38.83, 176.63) |

Table 4.7 shows the resulting welfare change for each of the investment scenarios in relation to the reference project, computed using equation 8from above. Results are presented for whole sample and the two sub-samples representing for urban and rural respondents.

The monetary values are the price representative households are willing-to-pay, on an annual basis, to have different types of renewable energy projects (indicated by different attribute levels), rather than the reference case of expanded fossil fuel power generation. The whole sample places the greatest value on offshore wind farms, with the major determinant the welfare change being the absence of air pollution and landscape impacts. The next most valued type of energy project is a small onshore wind farm. For a large onshore wind farm or a biomass power plant the willingness-to-pay is not statistically different from £0, with a confidence level of 95%. The most interesting aspects of the findings presented in Table 5 are the comparisons of urban and rural preferences. Urban residents show a positive willingness-to-pay for only the large offshore wind farm, whilst they show negative welfare for all other types of renewable energy projects. Rural respondents' welfare estimates are rather different and reveal a positive willing to pay for <u>all</u> the renewable projects proposed. The highest value is associated with the biomass power plant, with a major determinant being the level of employment associated with plant operation and agricultural production of the energy crops, whilst also of significance is the benefit to wildlife associated with expansion of growing biomass crops. The large offshore wind farm follows in importance, given the absence of negative impacts on landscape, wildlife, air pollution and the creation of 5 permanent jobs. The small onshore wind farm has a high willingness-to-pay value associated with it. The lower value for the small onshore wind farm is due to a moderate impact on landscape and the diminished creation of jobs. The large onshore wind farm is positively valued, even with the negative value of creating a high landscape impact. This can be interpreted as rural residents being willing to accept some diminished landscape quality to get better air quality and some new job opportunities.

**Test for Validity and Consistency**

It is important that respondents should demonstrate a consistent ranking order of the attributes, between sample groups and within the same sample group. For a study to have confidence in its results, specifically the identification of preferences and derived utility, the same ranking of attributes should be identified by alternative survey methods for the same sample group (Mitchell and Carson, 1989). If inconsistency in the rank ordering of attributes is found, potential problems may exist, on both theoretical and econometric grounds.

Several studies have been conducted which attempt to measure the accuracy, or validity, of monetary values derived by CE (Ben-Akiva, 1990; Swait et al., 1994; Loomis, 1996). These studies cover a range of testing methods; conducting 2 CV studies on the same issue on the same sample group; and re-surveying the same sample group at a later date to compare respondent values and preferences over time. A last method is to simply test if stated preferences match economic theory and match other studies which have examined a similar good. This last method is the basic premise upon which benefit transfer studies are founded.

The comparative studies approach, conducting alternative stated preference research simultaneously or consecutively, was deemed too time consuming and expensive for the choice experiment being conducted here. The same was true for the re-survey method.

Two methods of testing for consistency are identify and rank preferences in an secondary or alternative manner within the same survey instrument, and to examine decision making rationality of respondents by the profiles which are selected from the CE choice sets (Foster and Mourato, 2002). The first of these is an explicit test while the second is an implicit test. Respondent are aware of the test in the first instance and unaware in the second.

An explicit validation question was included in the questionnaire to test for a respondent's consistency with their stated preferences. Respondents were given a separate listing of the five attributes and asked to indicate which single attribute was most important to them.

**Figure 4.2** **Validation question presented in the CE survey**

| |
|---|
| Overall which of these impacts is most important to you? (Please tick only one)<br>Landscape______ Wildlife______ Air Pollution______<br>Employment______ Price of electricity______ |

The rank order of the attributes, as determined by respondent "votes" was: 1) air pollution;

2) wildlife;

3) electricity price;

4) landscape; and

5) employment.

Table 4.8 **Summary of Vote for Most Important Attribute**

| Attribute | Number of votes | Rank order | Rank order by Implicit Prices | Implicit Price |
|---|---|---|---|---|
| Air pollution | 142 | 1 | 1 | £13.84[#] |
| Wildlife | 35 | 2 | 2 | £4.94[#] & £10.95[#] |
| Employment | 31 | 3 | 4 | £0.19 |
| Landscape | 30 | 4 | 3 | £2.77, £3.36, £7.00[#] |
| Price of electricity | 51 | (2)** | * | |

* The implicit prices for the price coefficient will always equal 1, as the implicit price determined by dividing the attribute coefficient by the price coefficient.

** Ranking of price by votes.

[#] Statistically different from 0 at 95% confidence level.

For air pollution and wildlife consistency is demonstrated with the preference results shown in Table 4.8 above. The scale of the voting tally is similar in structure to the different in attribute values as shown by the implicit prices.

The second two attributes, employment and landscape, are in reversed order between the two measures of preference. The margin between the two is only one vote. However, the size of the margin between the implicit prices indicates there is a significant deference in preferences and utility. This is an indication of inconsistent preferences. This supports the finding of heterogeneous preferences, which is discussed elsewhere in this chapter.

Another validity test of results is the scope test (Mitchell and Carson, 1989). The scope test is basic preference theory that states that more of a good provides greater utility to a consumer so more is preferred, assuming not satiation (Varian, 1999; Banerjee and Murphy, 2004). Consistency with preference theory is demonstrated by the implicit prices found between levels for each individual attribute. For all attributes with multiple levels the estimated willingness-to-pay increases with an increase the quality of the attribute. The implicit price WTP for reducing landscape impacts goes up as the quantity of impact goes up, e.g. people are willing to pay more as greater mitigation occurs. The same is true for wildlife and air pollution, improved quality of air and wildlife occurs people are willing to pay more.

Another implicit test of validity and logical choice making was also conducted by examine the respondent choice behaviour in the survey. Hanley (2002) and Mourato and Foster (2002) examined the rationality of respondent choices when presented by a choice set which had a dominate/subordinate pairing. If the respondent is rational they will choice the superior profile.

One profile is said to dominate another profile when it the attribute levels are at least as good as the alternative profile's attribute levels (Foster and Mourato, 2002). Two choice sets were found to have dominant/subordinate pairing. Profile 22 was paired with profile 12 and profile 20 with profile 6 in the CE survey.

Profile 22 is superior to profile 12 when attribute levels are compared on the basis greater utility. Four attributes in profile 22, i.e., landscape, wildlife, air pollution, and employment, have attribute levels which are considered better (superior) that the levels present in profile 12. The price attribute is the same for both profiles. The superiority of profile

22 is confirmed by calculating the cumulative implicit price for each profile.

**Figure 4.3** **Choice Set (Profile 22 and Profile 12)**
**(Superior/Inferior paired profiles)**

| | Profile 22 | Profile 12 | Neither |
|---|---|---|---|
| LANDSCAPE | NONE | MODERATE | No increase in renewable energy |
| WILDLIFE | NONE | SLIGHT HARM | |
| AIR POLLUTION | NONE | SLIGHT INCREASE | Alternative climate change programs used |
| EMPLOYMENT | 8- 12 JOBS | 1-3 JOBS | |
| PRICE OF ELECTRCITY | £45 | £45 | North Sea gas fired power stations instead |

86 respondents returned surveys which included this choice set; 77 preferred profile 22, 6 preferred profile 12, and 3 preferred the "neither" option. Of the 83 respondents who selected a renewable energy plan, 93% stated a preference for profile 22.

Figure 4.4 **Choice Set (Profile 20 and Profile 6)**
**(Superior/Inferior paired profiles)**

| | Profile 20 | Profile 16 | Neither |
|---|---|---|---|
| LANDSCAPE | MODERATE | HIGH | No increase in renewable energy |
| WILDLIFE | SLIGHT IMPROVEMENT | NONE | Alternative climate change programs used |
| AIR POLLUTION | NONE | SLIGHT INCREASE | |
| EMPLOYMENT | 1-3 JOBS | 1-3 JOBS | North Sea gas fired power stations instead |
| PRICE OF ELECTRCITY | £16 | £45 | |

77 respondents returned surveys which included this choice set; 73 preferred profile 20, 2 preferred profile 16, and 2 preferred the "neither" option. Of the 75 respondents who selected a renewable energy plan, 97% stated a preference for profile 20.

The failure rate for the Profile 22/12 Choice Set is higher than the level found in Hanley et al., (2002), while the Profile 20/16 Choice Set failure rate is lower. The dominance/subordinate test shows that the population sample did overall provide logical and consistent preference revelation by the respondents.

The few respondents who failed the validity test, and thus did not give rational or consistent selections may be interpreted in a number of ways (Foster and Mourato, 2002). First, human decision-making does not conform to the economic model of rational choice. This is the prevailing view in the psychological literature. Second, human rationality is bounded by the complexity of real situations, so respondents make simplifying heuristics which may violate economic principles occasionally. Third, the design and measurement of the respondent in the choice experiment is a source of the irrationality, or in simpler terms, the experiment forced irrationality on the respondents by its design. The later two interpretations are discussed more thoroughly in the following chapter, in the sections on task complexity and state dependency.

These validity tests demonstrate the presence of respondent inconsistency and possible irrational preferences. This inconsistency is the likely cause of heterogeneity and the violation of the IIA assumption.

## Conclusion

Intermediate and remote rural areas of Scotland are facing problems of an ageing population and net out-migration of young people due to stagnant or declining local economies and a shortage of job opportunities. Rural economies can no longer rely on the agricultural sector as a source of employment and wealth. Diversification of the rural economy is thus essential to maintain the viability of rural population. This diversification in Scotland is increasingly coming from renewable energy schemes, encouraged by government intervention which has created financial incentives for renewable investment. However, the expansion of renewable energy sources is likely to have significant environmental and social impacts. In particular, renewable energy projects have impacts on landscape, wildlife, air pollution, electricity prices and job opportunities. The choice experiment method used in this paper enabled these effects to be jointly evaluated in welfare-consistent terms. Conclusions can then be more easily drawn about the net social benefits of different renewable energy investment strategies.

Our results suggest Scottish citizens generally support the expansion of renewable energy projects, in spite of the existence of heterogeneous preferences in regards to the potential costs and benefits of these projects. For the full sample, the implicit prices show the most valued attribute to be a reduction in air pollution. Secondly, respondents indicated significant importance to impacts on wildlife, especially for a change from slight harm to one of improvement. The costs of landscape change are generally significant if the project in question creates a high impact on landscape. There is no willingness-to-pay to reduce landscape impacts if projects are expected to have a low or moderate impact. In terms of ranking renewable energy projects, the whole sample population would prefer large off-shore wind farm projects, followed by small on-shore wind farm projects. The alternative of a large on-shore wind farm project is given the lowest utility and preference.

We also find important differences between urban and rural responses in this choice experiment. The implicit price analysis indicates that urban respondents have a positive willingness-to-pay for a landscape change from high impact to no impact, for a slight improvement in wildlife, and for a reduction in air pollution. Urban residents, though, placed an insignificant value on the creation of new permanent jobs from renewable energy projects. There is some evidence that negative landscape impacts from the development of projects are more acceptable to the rural population. Conversely, rural people value wildlife benefits and reductions in air pollution more highly than their urban counterparts (the last issue of air pollution may be from a perception that biomass combustion was more likely in rural areas, i.e., close to the supply of energy crops). Of particular relevance, employment creation is a statistically and economically significant attribute for the rural sample, which would be willing to pay an additional £1.08 per year per household for each additional full time job created by the renewable projects.

The welfare changes associated with the four alternative renewable energy projects reaffirm the differences in preferences between urban and rural dwellers. The urban group show a significant positive willingness-to-pay only for the large offshore wind farm project, whilst the rural sample stated a much higher willingness-to-pay for all the renewable project alternatives. The biomass power plant, which is characterised by an increase in air pollution, a moderate impact on landscape, an improvement in wildlife and the creation of 70 new permanent jobs, was given a very high willingness-to-pay (£ 97.95), especially when compared to the second best option (large off shore wind farm) which was valued at £ 53.71. This supports an interpretation that rural respondents value projects that improve job opportunities in their locale.

## Chapter 5

### *Methodological Issues in Choice Experiments*

**Chapter Sections**

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Task Complexity and Cognitive Burden

Literature Review

Discussion

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Literature Review

Discussion

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Discussion

## Introduction

This chapter will discuss some of the theoretical issues in conducting choice experiments and all stated preference research. Issues that are examined are task complexity and cognitive burden, state dependence, and incentive compatibility. All of these subjects can influence the accuracy of respondent's answers. If respondent's preferences are not truthfully revealed, either through confusion or strategic behaviour, the findings from stated preference survey are suspect, and any policy recommendations may (will) be based on inaccurate knowledge.

## Task Complexity and Cognitive Burden

Choice experiments are very complex survey instruments when compared to public opinion surveys and even many contingent valuation studies. The ability of survey respondents to understand all the attributes and their various levels, then compare these characteristics between different profiles, may be too hard a mental task for some people. So the question is asked,"Can complexity of the survey instrument be a source of inconsistency in responses?" If the answer is yes, than what can be done to improve the quality of responses? This section does not answer that question for the choice experiment conduct and reported in Chapter 4, but does illuminate the issues involved.

## Literature Review

Homo Economicus, or rational economic man (the assumption of rational human behaviour), was taken for granted for a very long time by economists, until Simon (1955) first questioned the validity of this key principle, noting that the assumption was often times clearly not seen in consumers.

In "The origin of predictable behaviour", Heiner identified that consumer's ability to process information had limits, and if these limits were exceeded, cognitive burden, could lead to non-rational decision making (Heiner, 1983).

During the past 20 years, since Heiner made that statement, research and economic experiments have been conducted to test the validity of Heiner's hypothesis concerning choice complexity and information limits. The results of that research does suggest the existence of a gap between the cognitive ability of decision makers and the cognitive burden (or cognitive requirements) of the decision process (Mazzotta and Opaluch, 1995). A test conducted by Mazzotta and Opaluch incorporated a complexity index in to their research. So the contingent choice task had an index included in the variance of the discrete choice model, thus making the complexity level clearly identifiable in the analysis. They found that complexity can influence the estimated coefficients from the model.

Behavioural decision theory is another field and source of literature that addresses the complexity question. The leading theories concerning the complexity of the decision environment are summarized by Payne et al. (1993). Generally, research in this area has attempted to assess how changes in the task environment impact the way respondents choose, how this leads to a wide range of choice strategies, and suggestions on how strategy selection processes depend on the trade-off between cognitive effort and outcome accuracy.

Bradley and Daly (1994) have treated the problem of complexity by combining both frameworks from above. The authors were the first to model task complexity in a random utility framework, recall from Chapter 4 that RUT is a foundation stone of choice modelling. The authors used the logit scaling approach to test for fatigue effects in rank-order data and concluded that the scale effect existed. Ortuzar and Rodriguez (2002) and Perez et al. (2003) both confirmed and demonstrated the rigor of Bradley and Daly's work by applying it to under circumstances.

Swait and Adamowicz (2001) studied the problem in depth by accounting for choice complexity and consumer behaviour through analysis of the scale factor, using an index of entropy which was linked to the experiments features.

At the same time, De Shazo and Fermo (2002) examined both complexity and consistency through a scale factor parameterisation, based on measurement terms that captured either the amount of information or the correlation structure of the data.

The final two economists who have attempted to identify the structure of choice complexity and cognitive burden are Hensher and Arentze.

Hensher investigated the influence of choice experiments design by examining the dimensionality of the choice set over the derivation of welfare estimates, such as the subjective value of time, by specifying multinomial logit and random parameter logit models which interacted between the design dimensions and the attributes (Hensher, 2004).

Arentze et al. (2003) examined the influence of task complexity in terms of the number of attributes, alternatives and choice sets presented, as well as the influence of presentation format (surveys with or without pictorial material) including the effects of considering a less literate population. This research found that both the presentation method and the literacy level had no significant impacts, while task complexity had a significant effect on data quality.

### Discussion

A significant quality of choice experiments is the ability to analytically disaggregate environmental goods or services into constituent attributes and levels, which are of interest to policy makers and researchers. The potential to derive distinct monetary values or exchange rates between those attributes, and the levels within each attribute, is an important expansion of non-market valuation techniques, such as contingent valuation method. It allows multiple hypothetical scenarios to be imagined and separate values estimated for each scenario, without the single value or whole picture constraint that is required by the use of contingent valuation studies.

A negative trade-off for this increased analytic ability is the increase in task complexity as experienced by survey respondents. Choice experiments present respondents with the task of choosing one preferred alternative out of several possible alternatives. These alternatives are described by common attributes and varying levels of the attributes (Swait and Adamowicz 2001a). The number of possible alternative scenarios demonstrates exponential growth as levels and attributes are added. In Chapter 4, with 17 levels among the 5 attributes, 360 possible scenarios could be constructed. Limiting this choice experiment to estimates of only main effects from a fractional factorial design, resulted in 25 profiles that had to be combined into choice sets. Adding one additional attribute with 3 levels, i.e., sound or noise level, would have increased the scenarios to 1080 and require 32 fractional factorial scenarios to estimate the main effects. To achieve a sufficient number of observations (stated choices) either the population sample size has to be increased or the number of choice sets presented to each respondent has to increase for all the choice sets to have sufficient opportunity to be compared. (Greene, 2003)

Respondents have limited information and time to contemplate their "best" choice. Swait and Adamowicz (2001) found that there is a systematic impact on estimated choice parameters as complexity of a survey instrument is increased. Respondents have limited resources to spend on a choice experiment, i.e., time, mental concentration, personal interest, prior knowledge of issue. As the complexity increases any one of the mentioned limitations, as well as other individual respondent specific constraints, ad infinitum, can motivate a respondent to choose simplifying strategies to complete the task. This can result in preferences being expressed with differing levels of variance.

Tversky and Shaffir (1992) found that large numbers of choice sets presented to individual respondents may facilitate both a learning effect and testing fatigue, both of which can increase the variability in choices.

A concern did exist in Chapter 4 about the amount of reading and learning required of the respondents to understand the issues being discussed, the attributes being analyzed, and the various levels assigned to each attribute. During pilot testing of the survey instrument, respondents stated that it took approximately eight to twelve minutes to read it, with completion of the four choice sets and the socio-economics questions taking another ten minutes. Large easy reading type face was used, as well as graphics and symbols, to make the survey visually interesting for the respondents (See Appendix A).

A final distinct question was asked at the end of the four choice sets presented in each survey. The question asked which single attribute was most important to the respondent. This question was used to test for consistency of answers by the respondents. The results of this question are discussed in Chapter 4.

## State Dependence

### Literature Review

State dependency deals with theories of decision making under uncertainty. It relates to situations in which an individual's choice of a course of action, by itself, does not determine the outcome.

Savage (1954) introduced what has become the standard analytical framework for analysing state dependency. It consists of three sets: 1) states of the world; 2) an arbitrary set of consequences; and 3) and the set of all the functions from the set of states to the set of consequences. The set of functions in the third set, labelled F, are referred to as acts and represent courses of action. The consequences in the second set, labelled C, describe anything that may happen to a person. And the first set, labelled S, represent all the possible resolutions of uncertainty, that is, "a description of the world so complete that, if true and known, the consequences of every action would be known" (Arrow, 1971). The decision maker will have different preferences for different actions based on the current state and the desired stated. These preferences can be ordered by and are transitive.

A preference relation is state dependent when the current state of the individual's world is itself of direct concern to the decision maker. For example, supporting the expansion of renewable energy is choosing an act whose consequences, the environmental and financial costs, depend on the decision maker's experience.

In this example, the state is the decision maker's environment, both ecological and financial. It affects the decision maker's well-being directly, and indirectly, through the benefits and costs received by the degradation or improvement to the decision makers environment. The preference relation may display ordinal state dependence, in which case the underlying state may affect the decision maker's preferences by altering his ordinal ranking of the consequences; or cardinal state dependence, by altering his risk attitudes; or both.

To define state dependence formally, it is convenient to adopt the model of Anscombe and Aumann (1963). In this model the state space is finite, and the consequences are lotteries, that is, probability distributions that assign strictly positive probability to a finite number of outcomes.

Preferences among acts are a matter of personal judgement, presumably combining the decision maker's valuation of the consequences and his beliefs regarding the likely realization of alternative events (that is, subsets of the state space). Subjective expected utility theory pertains to preference relations whose structures allow the decision makers' valuations of the consequences to be expressed numerically, by a utility function; his beliefs to be quantified by a (subjective) probability measure on the set of states; and the acts to be evaluated by the expectations of the utility of the corresponding on sequences with respect to the subjective probability. In other words, the theory depicts the decision makers' choice among alternative acts as expected utility maximizing behaviour.

The subjective expected utility representation separates risk attitudes, represented by the utility function, from beliefs, represented by the subjective probabilities. However, the uniqueness of the probabilities depends crucially on the premise that constant acts are constant utility acts. This premise is not implied by the axioms. In particular, state-independent preferences do not imply state-independent utility function.

An alternative analytical framework postulates the existence of a preference relation on hypothetical lotteries, whose prizes are outcome-state pairs. This preference relation is assumed to satisfy the axioms of expected utility and to be consistent with the actual preference relation on acts. Because the hypothetical lotteries imply distinct, hence incompatible, marginal distributions on the state space, preferences among such lotteries are introspective and may be expressed verbally only as hypothetical choices. Decision makers are supposed to be able to conceive of such hypothetical lotteries and to invoke, for the purpose of their evaluation, the same mental processes that govern their actual decisions.

Other theories that yield subjective expected utility representations invoke preferences on conditional acts (that is, preference relations over the set of acts conditional on events). Fishburn (1973) advanced such theories assuming consequence sets that have distinct structures. Skiadas (1997) proposed a non expected utility model, based on hypothetical preferences, which yield a representation with state-dependent preferences. In this model, acts and states are primitive concepts, and preferences are defined on act-event pairs.

For any such pair the consequences (utilities) represent the decision maker's expression of his holistic valuation of the act. The decision maker is not supposed to be aware whether the given event occurred; hence his evaluation of the act reflects, in part, his anticipated feelings, such as disappointment aversion.

Drèze (1985) presented distinct theories of individual decision-making under uncertainty with moral hazard and state-dependent preferences. Both assume that decision makers can exercise some control over the likely realization of events.

Drèze does not specify the means by which this control is exercised, relying instead on their manifestation in the decision maker's choice behaviour. In particular, departing from Anscombe and Aumann's (1963) "reversal of order" assumption, Drèze assumes that decision makers strictly prefer that the uncertainty of the lottery payoff be resolved before that of the acts, presumably to allow them to exploit this information by taking action to affect the likely realization of the underlying states. Drèze obtains a unique separation of state dependent utilities from a set of probability distributions over the set of states of nature. Choice is represented as expected utility maximizing behaviour where the expected utility associated with any given act is itself the maximal expected utility with respect to the probabilities in the set.

Dreze replaces the state space with a set of effects, phenomena on which decision makers can place bets and whose realization they can influence by their actions. In Dreze's theory the choice set consists of action-bet pairs.

Actions affect the decision maker's well-being directly (e.g., actions may correspond to levels of effort) and indirectly (through their impact on the decision maker's beliefs); bets are functions from effects to monetary payoffs. Dreze gives necessary and sufficient conditions for the existence of subjective expected utility representations with unique, action-dependent, subjective probabilities; effect-dependent utility functions representing the evaluation of wealth; and a distinct function that captures the direct impact of the choice of action on the decision maker's well-being.

As with state-independent preferences, the economic analysis of many decision problems involving state-dependent preferences requires measures of risk aversion.

**Discussion**

State dependence can be of concern when investigating the non-market valuation of environmental goods. Preferences revealed by the respondents may be significantly determined by prior experiences, knowledge and pre-existing attitudes. Common difficulties that can arise in surveys from state dependency are yea-saying, the bandwagon effect, strategic answering, and spontaneous use of simplifying heuristics when preferences are stated. It is of interest because of the rarity of the "Neither" option being chosen in Chapter 4 and the size of the ASCs derived in the full sample model. Both of these can be inferred to indicate a large positive preference for renewable energy. State dependency may also explain one source of the heterogeneity of preferences found in Chapter 4. (Seetharaman, 2004)

There are several types of state dependency. Structural state dependency is the continuation of the existing preference state. This preference can be either positive or negative in its expression. The former being labelled "inertia" because it continues in its present form. The later being called "variety-seeking" because it continually changes for novelty reasons. Structural dependency is commonly found to be the dominant form; it is the major determinant of future choices by consumer (Seetharaman, 2004).

Other types of state dependency are habit persistency and carryover effects. Two forms of habit persistency are identifiable by serial correlation. The first type is identified from serially correlation of the error terms in the random utility function. The later type is identified as serial correlation of utility maximizing behaviour on successive preference decisions of consumers. Both of these are derived from lagged utility.

For example, while there is generally positive support for green energy consumption in Great Britain (BWEA, 1996; Social Research, 2002; MORI, 2003) there has been very low voluntary participation in commercial markets for green energy. There is perceived utility, but too much state inertia to create behavioural changes. However, with mandatory purchases under the ROS program, minimal opposition has occurred and there seems to be satisfaction with the new state. Roy, et al., (1996) proposed that state dependency evolves within a random utility function in a Markov fashion[1]. Roy believed that there was no set or

[1]A Markov chain is a sequence of random values whose probabilities at any specific time interval depends upon the value of the number at the previous time. The controlling factor in a Markov chain is the transition probability; it is a conditional probability for the system to go to a particular new state, given the current state of the system.

predetermined probability of transition of the population to a new state, rather there was an interval of probability and any particular value for a specific transition was randomly drawn from that interval.

In other words, the inertia that existed within the population for not voluntarily purchasing green energy may have been over come with sufficient time, as there was a positive preference to move in the direction of green energy consumption. However, the incremental movement was too slow and too erratic, so the government forced a very large and involuntary transition to indirect participation in a green energy program. It is possible that the growth of green attitudes and preferences could have lead to viable green energy markets, but the ROS program has forced a new utility choice that Scottish consumers seem to be accepting and supportive of.

The carryover effect is the lagged effect of information provision, in the case of commercial markets this can be the effect of marketing and advertising, for non-market environmental goods it can be education and information provided by interested parties, i.e., environmental groups and governments.

State dependency is an important aspect to consider when conducting stated preference valuations. There are many emotionally charged issues tied to electric energy production. Some of which are the use of nuclear energy, global climate change, general air pollution, the decline of the Scottish coal industry, the landscape change with 120 metre tall wind-turbines with co-incidental harm to wildlife, destruction of fish habitat by hydroelectric schemes, to name a few negative associations. Positive associations with renewables range from wind farms being perceived as kinetic art on the landscape, a tangible fulfilment of technological optimism, greater self-determination from using local resources, rural development, and leaving a better environmental endowment for the future.

In one of the CE focus groups that were conducted, one participant commented on the imbalance in the distribution of costs and benefits of the Scottish-English relationship over energy, North Sea oil, nuclear power plant locations, and who really needed renewable energy the most.

There are implications of studying issues which contain a large emotional element for the respondent. Basic assumptions and axioms about utility and preferences for respondents may not hold true (Binger and Hoffman, 1998).

For example, behavioural assumptions may become uncertain with yea and nea-saying not being strategic behaviour, but rather expression of lexicographic preferences, as well as, rational utility maximizing may not occur or be consistent (Elster,1998) (Sunstein, 2003).

**Incentive Compatibility**

A choice experiment or any stated preference research is said to be incentive-compatible if it creates a situation where it is in the respondent's best interests to reveal their true preferences for the good, and he will not be tempted to engage in free-riding behaviour (Mitchell and Carson, 1989).

## Literature Review

Paul Samuelson (1954) concluded that free-riding behaviour would always be the individual's optimal response, regardless of which question format was used. This assumption contributed to arguments against the CV method and other stated choice tools. However, the assumption that individuals will always choose to free-ride has been questioned by several authors including Dreze and Vallee Poussin (1971), Clarke (1971), Groves and Loeb (1975), and Groves and Leydard (1977).

Dreze and Vallee Poussin (1971) demonstrated that a social welfare maximising government may achieve a Lindahl-Pareto equilibrium using individuals' marginal WTP in a continuous incremental dynamic Walrasian tatonnement process.

Clarke (1971), Groves and Loeb (1975), and Groves and Leydard (1977) developed a set of incentive-compatible methods fro revealing demand by the use of taxes, subsidies, or side-payments; these methods create a hypothetical scenario where it is in the individual's best interest to reveal his true WTP.

Akerlof (1983), and Akerlof and Dickens (1982), countered the assumption that strategic behaviour is costless beyond the immediate choice before the individual, building a model of honesty and cooperative behaviour in which honesty leads to long-run economic gains that may be lost if dishonesty and non-cooperative behaviour occurs.

Experimental economics has also contributed to the body of work showing the free riding should not be assumed to be the optimal behaviour for respondents. Experiments by Babb and Scherr (1975) compared three elicitation methods for WTP for a concert series and additional books for a college library: 1) the Clarke tax, 2) another incentive-compatible demand revelation method, and 3) a voluntary revelation method. Their research found the voluntary method resulted in the largest real payments, surpassing the two incentive-compatible demand revelation methods. Many economists discounted these results as coming from a poorly designed experiment, due to the novelty factor, induced altruism, insufficient incentives, and lack of experience by experimental subjects with the incentive-compatible methods.

However, Johansen (1977) maintained that there was little empirical evidence to support free-riding behaviour and suggested that economists may have overestimated the importance of such behaviour.

Experiments conducted by Vernon Smith et al. (1977, 1980), regarded as more realistic, failed to refute the earlier findings of Babb and Scherr (1975). Smith's work suggests that both incentive-compatible and voluntary demand revelation methods eventually achieve cooperative behaviour, and cooperative behaviour is often reached more quickly with voluntary mechanisms.

Mitchell and Carson (1989) suggest that theoretical results supporting incentive-compatible methods rests on several assumptions that do not seem to hold: zero costs to determining one's optimal strategy, zero costs to the act of responding dishonestly, and that the individual perceives no risk that his actions may prevent an optimal competitive or cooperative strategy.

Research exploring the incentive compatibility of numerous elicitation methods suggests that a commonly used CV method format can induce the respondents to reveal their true preferences. Zeckhauser (1973), and Hoehn and Randall (1987), demonstrated that the discrete choice "take-it-or-leave-it approach" for the provision of a public good at a set price is an incentive-compatible mechanism; it is in the respondent's best interest to answer 'yes' if their willingness-to-pay is greater than or equal to the stated price. However, the belief that the dichotomous choice CV method format is incentive-compatible has been challenged by more recent literature (Cummings and Taylor, 1999; Taylor, 1998) that suggests that in order for a dichotomous choice referendum to be incentive-compatible, it must be a closed referendum.

**Discussion**

How to motivate respondents of a stated preference survey to give accurate and truthful responses is not clear or resolved in the literature. The hypothetical nature of stated preference surveys leaves opportunity for participants to answer in a manner that can influence the total sample estimates, yea-saying or nea-saying being the most clear example of such behaviour. To avoid strategic responses, or attempted manipulation of results, it is important to present a payment mechanism which respondents believe is credible. Mitchell and Carson (1989) state that if a respondent perceives they could actually end-up having to pay for the environmental good in question, they will be motivated to give true responses about utility maximizing choices.

Research into CV incentive compatibility has not found conclusive evidence for mechanisms which assure respondents do not have hypothetical bias in their answers. If any results are conclusive, it is that CV estimated values will have some level of uncertainty in them. There seems to be a general attitude among CV critics to expect value estimates to be higher than the true WTP. But some researchers have found CV estimates of WTP were lower than revealed preference estimates on average for those studies that comparables could be found or developed.

Choice experiments have the same concern over hypothetical bias. In a Carlsson and Martinsson (2001) study which compared hypothetical and actually marginal willingness-to-pay donations for an environmental project, no significant differences were found. Although slight real differences in donations did exist between the actual and hypothetical. Internal validity testing was positive and supportive of the estimated CE results.

In the choice experiment presented in Chapter 4, a conscience attempt was made to present the hypothetical choice scenario in a realistic and credible manner. A believable government policy to move towards a cleaner environment was described. The object of this realism was to minimize hypothetical bias and improve incentive compatibility.

The make the respondents believe their answers were important and could contribute to a better understanding of what path the Scottish population want to take on renewables the introductory cover letter stated, "this research will be published and made available to the public, conservation groups, government, industry and anyone concerned for Scotland's future." They were also told that they were part of a select group who were being surveyed to find this information out. See cover letter in Appendix A.

Electric utility bills were the designated mechanism for collecting (if WTP) or dispersing (if WTA) payments. This is a real, accurate and universal mechanism that respondents could understand. Also, it is a non-discretionary payment method; respondents would have no choice but to participate.

There are no clear indications in the study if incentive compatibility was a problem or not.

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# Optimal Policy Goals for Tradable Green Certificates in an Electric Power Market with Strategic Interactions between Firms

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**Chapter Sections**

Introduction

Current Literature

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## Introduction

In this chapter the interactions between the market price of electricity, the renewable energy quota imposed on non-renewable power producers and tradable green certificates (TGC) are examined. These three components are the key elements of the Renewable Obligation (Scotland) (ROS) program which has been described in detail in Chapter One. The goal of this chapter is to determine if the price criteria and policy instruments, quota and TGCs, chosen by the Scottish Executive to motivate expansion of renewable power sources in Scotland are being used efficiently.

These three policy variables interact in a manner which determines the amount of indirect monetary subsidy transferred to renewable energy producers and the financial cost imposed on electricity consumers. Two critical motivations for the ROS program were the need for rapid deployment of renewable power technology, on a commercial scale[2], balanced against a political requirement that increases in costs resulting from the deployment do not exceed some unspecified level. A price level in monetary terms has never been stated by the government or any policymaker but can be described as a "politically acceptable" level that does not lead to voter dissatisfaction.

A mathematical model of the interacting electricity and TGC markets are presented with the ambition of evaluating the efficiency of the

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[2] Commercial scale is generally considered to be generator with 775 kW DNC or greater (Casazza, 2003).

ROS program, or if there is a superior method by which the same criteria and policy tools (price, quota, and TGCs) can motivate the expansion of renewables. Efficiency in this context is described as the timely deployment of renewable electricity technologies at an acceptable cost to consumers.

This chapter contributes to the field of renewable energy economics in several areas. All published literature and research which the author came upon makes the assumption of competitive markets for both the physical commodity (electricity) and TGC markets. This chapter does not assume competition; rather it assumes a complex relationship between a dominant player and subordinate player(s) in a Stackelberg relationship. This complex relationship adds to the literature as it portrays the regulatory and commercial markets in a more accurate manner, in particular to Scotland. While energy deregulation is being promoted in many regions of the world, full competition in power industry markets is still rare in all but a few developed economies and non-existent in less developed or transitional economies. Also, the relationship between the dominant firm and subordinate firm(s) is not a standard Stackelberg relationship of ceding market share from one firm to another. The inclusion of a TGC market imposes a secondary transfer of cost and revenue from the dominant firm to the subordinate firm(s), respectively, which affects the quantity of power production decision of the dominant firm.

The chapter proceeds as follows; Section 2 presents the prior literature investigating the use of TGCs, Section 3 describes the general strategic game to be played and relates its structure to actual operating power and TGC markets, Section 4 discusses the general Stackelberg game and the concept of backward induction, Section 5 is the presents the model, Section 6 presents an ad hoc comparative statics analysis, whilst the final section presents conclusions which can be drawn from the analysis.

**Current Literature**

Even though much of the world is still dominated by monopolistic franchises, significant government regulation, or outright government ownership of the electric power system, the economic literature on tradable green certificates tends to assume liberalized power markets and competitive firms.

In Jensen and Skytte (2002) the market price for TGCs and the obligation quota set by the State give ambiguous results as far as consumer welfare. The cross subsidy of the TGCs may lead to increased total power production and a lower market equilibrium price at some quota levels, but at higher quota levels electricity prices will be higher than the 'no program' case. It is also noted that energy conservation is made more difficult if the quota is set in the range where lower power prices occur.

Liberalized power markets and increasing deployment of renewable energy technologies are somewhat opposing goals (Morthorst, 2000). If competitive markets are allowed to select the most efficient provider of wholesale power than new renewables technologies will not grow in capacity as their costs are generally greater than traditional sources or power. TGCs are one method of overcome this cost difference. Morthorst contributes to an understanding of the risks involved in TGC markets and the possibility of highly volatile prices.

Both Lemming (2003) and Morthorst (2000) identify then discuss an important drawback of most renewables technologies, stochastic production cycles. Stochastic production is the uncontrollable variability in delivering power to users, it is also called intermittency. Renewable electric power is produced when the fuel resource (wind, water, sunlight, etc.) for generating is made available by nature and nature is not consistent over time. An additional drawback discussed by both authors is that commercial scale renewables projects tend to have very high capital investment costs coupled with low operating costs.

These characteristics of renewables projects create two significant uncertainties for investors in renewables projects. The first uncertainty occurs when renewables experience low production in one period, i.e. abnormally calm winds for wind turbines, and thus produce less electricity and earn fewer TGCs. A scenario is created where traditional power firms produce and sell more electricity to cover the absence of renewable power, but as a result of this increased production, the firms will demand more TGCs. Therefore significant correlation will exist between increased demands for TGCs at a time of decreased supply (Morthorst, 2000).

Both Morthorst (2003) and Nielsen and Jeppesen (2003) show that green certificates have been effective in increasing deployment of renewables in many European nations and meeting national goals for GHG emissions reductions.

Nielsen and Jeppesen (2003) discuss the movement in Europe towards a unified TGC market because of its effectiveness to date. They go on to show that political objectives of the individual national programs which are not harmonized within an European TGC system would operate with significant arbitrage potential and be economically inefficient. Morthorst (2003) adds that proposals for an EU-wide TGC market may make individual national targets for $CO_2$-reduciton more difficult. Those countries with higher TGC quotas, and resulting higher prices for certificates, may motivate greater investment than nations with lower quotas and lower TGC prices.

A static equilibrium model which takes into account TGCs, $CO_2$-emissions, import and export of electricity, effects on consumer and producer surplus changes for the Danish Green Certificate System was constructed by Amundsen and Mortensen (2001). The author's most important finding was that green electricity capacity was reduced in a scenario of increased $CO_2$-emission constraints because traditional generators would constrict production and therefore demand fewer green certificates. This Danish model came to the same conclusion as Jensen and Skytte (2003) that TGC quotas and markets have ambiguous effects on consumer and producer welfare. The potential loss or gain in welfare being especially sensitive to the quota determined by the government.

## The Model

### Introduction

This model represents a simplification of actual regulatory and commercial markets that operate in Scotland and the United Kingdom. While the model has features which apply to European and American markets, it is primarily meant to model Scotland and the regulatory and industrial structure therein.

The model will be presented in the following order:

Identify and describe the players

State important assumptions about player behaviour and market structures.

Describe the two markets that are of concern.

The regulatory regime requiring compliance.

The order of play.

After the model has been presented the Stackelberg Game and backwards induction path are briefly described. Than detailed mathematical expression are given and described for the players, markets and economics behaviours which represent the hypothetical TGC market.

Comparative Statics are used to evaluate the State's policy options and examine the optimality of providing the lowest priced electricity with the greatest expansion of renewable energy sources. The results of the comparative statics are used in an ad hoc analysis, to identify how real power and TGC markets might actually behave.

### The Players

There are three players:

Player 1 – The State

The State regulates the electric power industry. The objective of the State is to balance dual objectives of increasing renewable energy production without excessive diminishment of consumer surplus. This player may be referred to as: the State, the government, or the regulator.

Player 2 – The Brown Firm

A firm which is the dominant producer of electricity in the market place and can exercise influence over the power market. This firm uses only non-renewable fossil fuels (oil, coal, natural gas) as input for electricity generation, with resulting carbon pollution. The dominant firm operates under a profit maximising objective. This player is referred to as: the dominant firm or the Brown Firm.

Player 3 – The Green Firm

A series of small firms which are similar in quality and size; they may be considered as one firm or many in this analysis depending on the scenario. The firms produce electricity using only renewable fuels (hydro, wind, biomass, etc.) for generation and are a price-taker in the power market. Each firm has insufficient production capacity to influence the electricity market, but may have influence in the TGC market. All of the firms operate under a profit maximising objective. These players may be referred to as: the fringe firm(s) or the Green Firm(s).

**Assumptions**

1.) *Both the TGC and power markets operate as open public bid/offer exchanges where buyers and sellers are matched then exchanges completed as bilateral transactions. This minimizes the search and information costs in the market.*

Thus it is assumed that:

<u>There are no market transaction costs for players</u>.

2.) *As new renewable generation facilities are built and made operational the TGCs from the Green Firm are sold to the Brown Firm under long term contracts (12 - 20 years). The electric power is sold to consumers either through the spot market (immediate or short-term contracts) or long term market (12-20 years contracts). Both TGC and power markets clear each period at an equilibrium quantity and price. For each succeeding iteration of play only the new capacity deployed by the Green Firm that period is available to the TGC and power markets. TGCs issued or transacted in prior periods do not influence current play.*

Thus it is assumed that:

<u>The game may be played in multiple iterations, but the equilibrium price and quantity established at the end of each round are fixed and cannot be re-negotiated in later periods</u>.

and

<u>There is no banking of TGCs between periods. Every TGC issued in a period must be sold within that same period or it becomes void</u>.

3.) *No trans-national markets for TGCs currently exist in Europe. No country recognises the validity of TGCs issued in another jurisdiction. Distinct TGC markets do exist for Scotland versus England and Wales, yet TGCs issued under either authority may be traded on both markets. Electricity is widely traded between countries in continental Europe, but only relatively small quantities are traded between Great Britain and the continent.*

Thus it is assumed that:

This game is played as a closed economy.

4.) *In the United Kingdom and most European countries TGC programs allow for Brown Firms to choose between submitting TGCs to the appropriate regulator or pay an equivalent fee in replacement of the certificates. The reason for this is that transaction costs do actually exist for firms (in contradiction to assumption 1 above) and thus it allows for firms to determine their own most efficient means of complying with the TGC regulations. It can be hypothesised that non-pecuniary costs and benefits motivate a firm to use TGCs, i.e., to appear compliant and supportive of environmental programs.*

Thus it is assumed that:

The Brown Firm has a weak preference for using TGCs to meet the government obligation versus paying the buyout fee.

**The Markets**

There are two markets that operate in this model. The first is a market for electricity. This is a normal commodity market that has sellers and buyers of a good. There are many buyers of the good, none of whom can exercise market power or influence; buyers of electricity are of no concern to this analysis.

However, on the sellers side of the market there is one dominant firm which controls a large and significant share of total production, and actively influences the market through its production decisions. It is aware of it ability to influence the electricity market. This dominant firm is the Brown Firm.

There are a series of small producer firms who have no market influence and perceive themselves as price takers in the electricity market. They are all similar in size and quality and may be aggregated and treated as a single firm for most purposes in this analysis. This aggregated firm is the Green Firm.

Thus the <u>first market</u> is:

<u>A Stackelberg duopoly electric power market</u>.

The second market is for TGCs. There is only one buyer of TGCs, the Brown Firm. The Brown Firm purchases the TGCs and submits them to the State, per regulatory mandate; a pre-established percentage of the Brown firms production must be matched by either TGCs or a monetary buyout premium must be paid to fulfil the regulations. The Green Firm is the only seller of TGCs; by State fiat the green Firm receives one TGC for each unit of electricity that it produces and has the right to sell the certificate into the TGC market.[3]

Thus the second market is:

A non-competitive market for TGCs. The Green Firm is a seller of TGCs and the Brown Firm acts as a monopsonist.

The electricity market is cleared first. This fixes the quantity of power which was produced and sold in the market; the TGCs, which are equal to quantity of renewable power produced, are than issued to the Green Firm by the State. The TGC market is cleared second with an inelastic supply of TGCs and an inelastic demand by the respective firms.

Thus the order of market clearance is:

1.) The electricity market, 2.) The TGC market.

**State Regulations**

In order to promote renewable energy the State has initiated a TGC market. This market exists only by decree of the government. It has mandated that the Brown Firm must submit TGCs, or the equivalent, to the State as an operating licensing requirement. The State issues TGCs only to licensed electricity producers, the Green Firm, who use renewable fuel sources. There is no cost imposed on the Green Firm by the State. The Green Firm may sell these TGCs.

1. The Brown Firm is obligated to submit TGCs to the State in an amount equal to a pre-determined percentage of the

[3] Note that the Green firm is not a monopolist, as it is an aggregation of many individual small firms who behave the same as price-takers, but do not have market awareness to act in collusion and create a monopolistic cartel.

firm's annual electricity sales based on physical quantity transacted, not monetary value. The obligation percentage is determined by the State and announced in advance of any play.

2. The Brown Firm has the option, management discretion, of submitting a buyout fee in substitution of TGCs to the State. The buyout fee is pre-determined by the State prior to each interaction of the game and is known by all players.

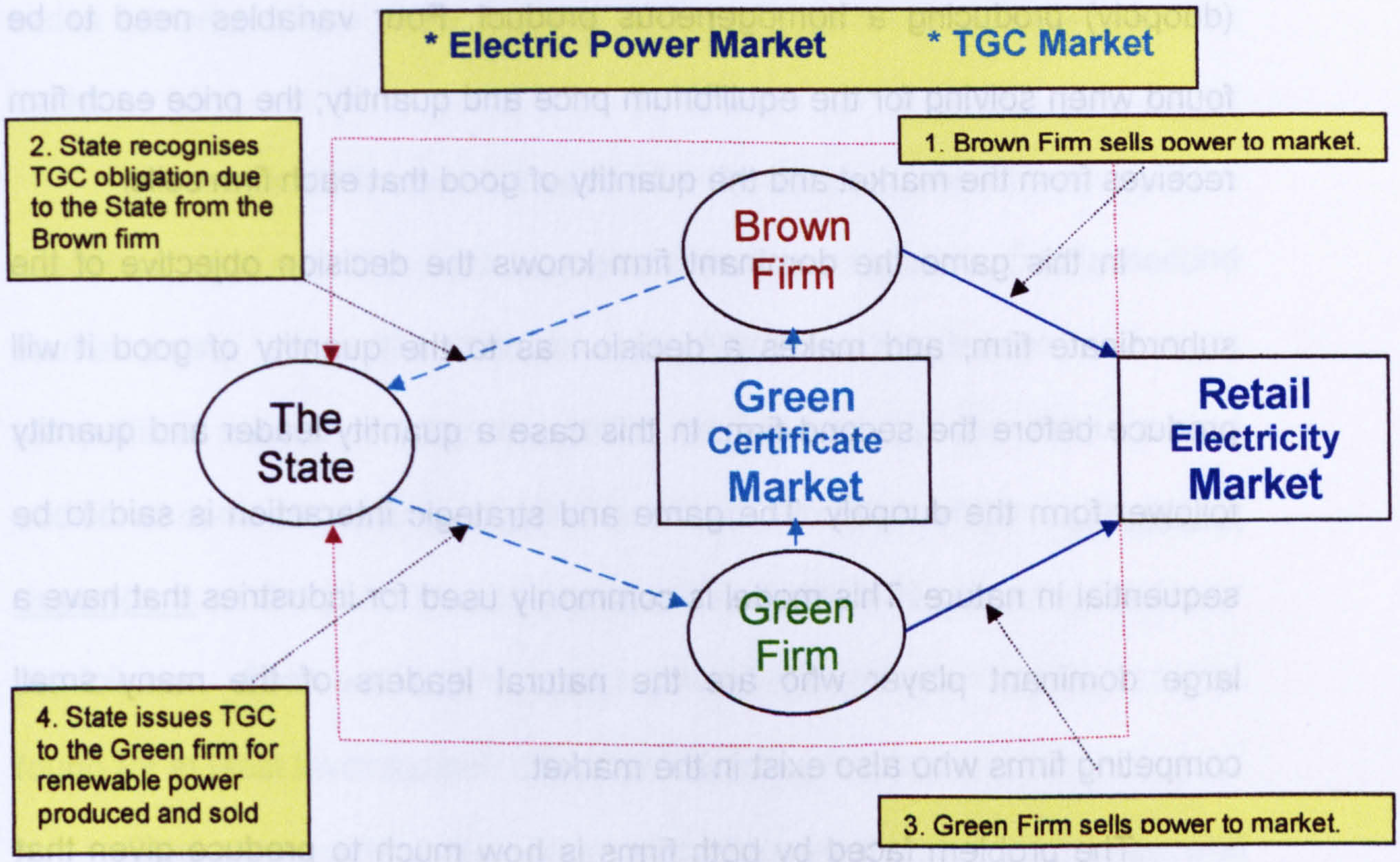
**Order of Play**

The first player to move is the State, who declares the values of the two policy variables, the obligation percentage and the buyout fee. Additional information made known includes the forecasted market demand for electricity, the production capacity of the Green Firm, and the production capacity of the Brown Firm. All this information becomes common public knowledge.

The next player to move is the Brown Firm, who determines its profit maximizing quantity of electricity production given its knowledge of the Green Firm's reaction function (maximise profits and act as a price-taker) and the values of the two TGC variables.

The third player to move is the Green Firm, who determines its profit maximizing level of production, given the market price for electricity and the market for TGCs.

**Diagram 6.1 – Flow Chart of Transactions for Tradable Green Certificates Market and Electricity Market**




The electricity and TGC markets operate as follows: 1) Both the Brown and Green Firms generate power and sell to consumers; 2) Both the Brown and Green Firms report their production quantity to the State; 3) The State obligates the Brown Firm to submit TGCs or equivalent buyout funds to the State, based on production; 4) The State issues TGCs to the Green Firm, based on production; 5) The Brown Firm may purchase TGCs in the TGC market to meet obligation.

The TGC program results in the Green Firm earning revenues from two sources, electricity and TGCs. The TGCs create new revenue sources with no associated production costs. The Brown Firm has increased costs from meeting the TGC obligation by either purchasing TGCs or paying a buyout equivalent.

## The Stackelberg Game[4] and Backwards Induction Path[5]

The Stackelberg model is a game of strategy between two firms (duopoly) producing a homogeneous product. Four variables need to be found when solving for the equilibrium price and quantity; the price each firm receives from the market and the quantity of good that each firm sells.

In this game the dominant firm knows the decision objective of the subordinate firm, and makes a decision as to the quantity of good it will produce before the second firm. In this case a quantity leader and quantity follower form the duopoly. The game and strategic interaction is said to be sequential in nature. This model is commonly used for industries that have a large dominant player who are the natural leaders of the many small competing firms who also exist in the market.

The problem faced by both firms is how much to produce given that the market price is determined by the total quantity produced by both firms. However, there is a significant difference between the two players. The leader knows the follower will only react to market conditions, quantity being sold by the leader, and that the follower will be a price-taker in the market for the entire product it can generate. This is called the conjectural variation or the reaction function of the follower. The leader chooses a level which

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[4] The game is named after H. von Stackelberg who published this model in his book, *Marktform und Gleichgewicht*, 1934.

[5] The Stackelberg game and backwards induction are standard material in almost all intermediate level microeconomic textbooks and certainly in introductory game theory textbooks. The author gives specific citations where appropriate, otherwise the material is considered generally available knowledge and no citation given.

maximises its profit while recognising the quantity produce by the follower and its effect on market price. Described in the simplest terms the leader cedes a market share to the follower which will maximise the profits for the leader.

The major difference between the Stackelberg model and solution described here and the model proposed in this chapter is that a second market exists where the follower sells TGCs to the leader in a non-competitive market. Additional profits are earned by the follower and additional costs are incurred by the leader in a manner which is **not solely dependent** on the profit maximising quantity decision of either the leader or the follower. Even with this second market the equilibrium solution can be found (or at least investigated) using backwards induction.

Stackelberg games are solved using backward induction. The general solution finds the price and quantity which occurs at equilibrium. The equilibrium quantity is divided between the Brown Firm and the Green Firm.

Backwards induction occurs in the following order:

i. Solve for the fringe-follower's reaction function; the quantity of renewable energy production given the quantity of electricity production by the dominant firm.
ii. Solve for the dominant firm's profit maximizing quantity of production given its knowledge of the fringe-follower's reaction function.
iii. Solve for the production quantity to maximize profits for the fringe-follower firm given the production quantity chosen by the dominant firm.

iv. Solve for the equilibrium market price and quantity of electricity.

In this paper a final step is added:

v. Solve for State policy variables to optimize consumer surplus and expansion of renewable energy production.

## The Mathematical Model

### Parameters

| | |
|---|---|
| $P_e$ | market price of retail electricity |
| $Q_e$ | total quantity demanded for electricity; $(q_r + q_d)$ |
| $P_c$ | market price for tradable green certificates |
| $q_d$ | quantity electric power produced by Brown Firm |
| $q_r$ | quantity electric power produced by Green Firm |
| $q_c$ | quantity green certificates produced |
| $\alpha$ | percentage portfolio obligation for year |
| $\Phi$ | buyout price for green certificates, as set by the State |
| $\alpha q_d$ | total amount of green certificates obligation |
| $\beta$ | maximum price of retail electricity that is politically accpetable |

**Market for Electricity**

The market for electricity is assumed to be non-competitive within certain regulatory parameters established by the State[6]. The Brown Firm perceives a downward sloping demand curve which means that it has market influence; if the Brown Firm changes it production quantity, the market price will change. Other qualities of the demand curve are that it is smooth and continuous; there is a market for all production at some price level, and the market functions as if electricity is a normal good.

Therefore the demand curve has the following properties:

i. $P_e(Q_e)$ is defined and continuous on $Q_e$.
ii. $P_e(Q_e) \in (0, \infty)$.
iii. There is a $\overline{Q}_e > 0$, such that $P_e(Q_e) = 0$ for $Q_e \geq \overline{Q}_e$
iv. and $P_e(Q_e) > 0$ for $Q_e < \overline{Q}_e$.
v. $P_e(Q_e)$ is twice differentiable; $P_e'$ and $P_e''$.

The Green Firm perceives a market demand curve which is perfectly elastic and no market influence exists. All energy produced by the Green Firm can be sold at an exogenous price to the dominant firm. The Green Firm is a price-taker.

[6] The regulatory parameters are not discussed here as they are not relevant to the model, other than to say that the State limits abusive business practices by energy firms, as electricity is classified as an essential good for social welfare. See literature on energy poverty and information from Ofgem for Scotland and the United Kingdom for more information.

**Market for Green Certificates**

The quantity of TGCs issued by the State to the Green Firm is exactly the same quantity of power that the Green Firm has delivered to the market, where $q_c$ is the quantity of TGCs and $q_r$ is the quantity of renewable power.

$$q_c \equiv q_r \qquad (6.1)$$

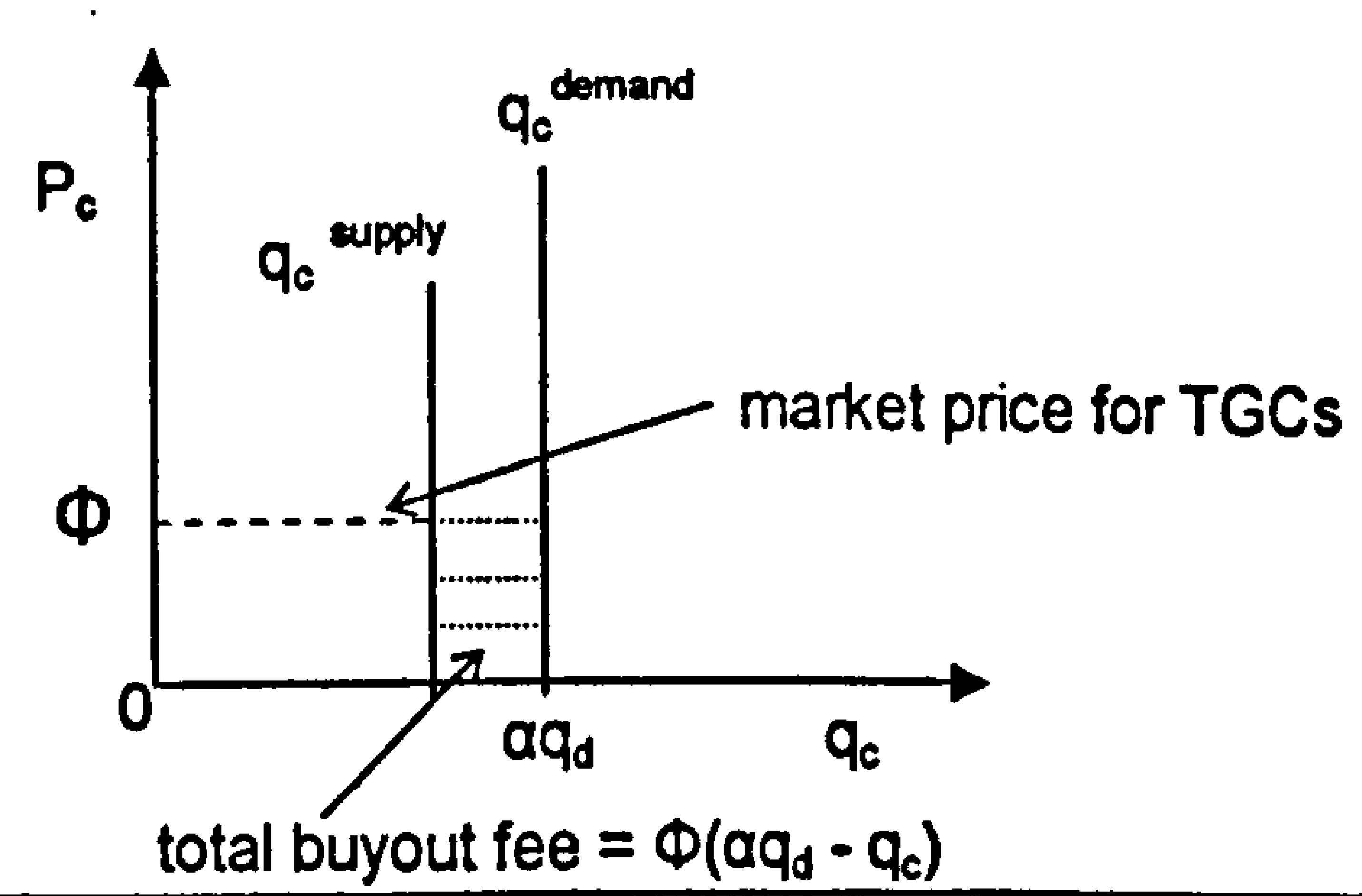
The Green Firm will be issued a TGC from the State for each unit of electricity (MWh) produced and sold in the retail market to consumers.

A single market exists for TGC with the Brown Firm as buyer, monopsonist, and the Green Firm as seller.

If the quantity of TGCs available in the market are less than or equal to the obligation requirement of the Brown Firm, the TGC price will be equal to the buyout fee.

$$\text{If } q_c \leq \alpha q_d, \text{ than } P_c = \Phi \qquad (6.2)$$

Diagram 6.2 Market for Green Certificates, $q_c^{supply} < q_c^{demand}$




This diagram illustrates the market for TGCs during one period of play, after the electricity market has already been cleared. The quantity of TGCs demanded by the Brown Firm is fixed, as is the quantity of TGCs supplied by the Green Firm. All TGCs available will trade at a price equal to the buyout fee. In this case, there is a shortage of TGCs, and a buyout will have to be paid.

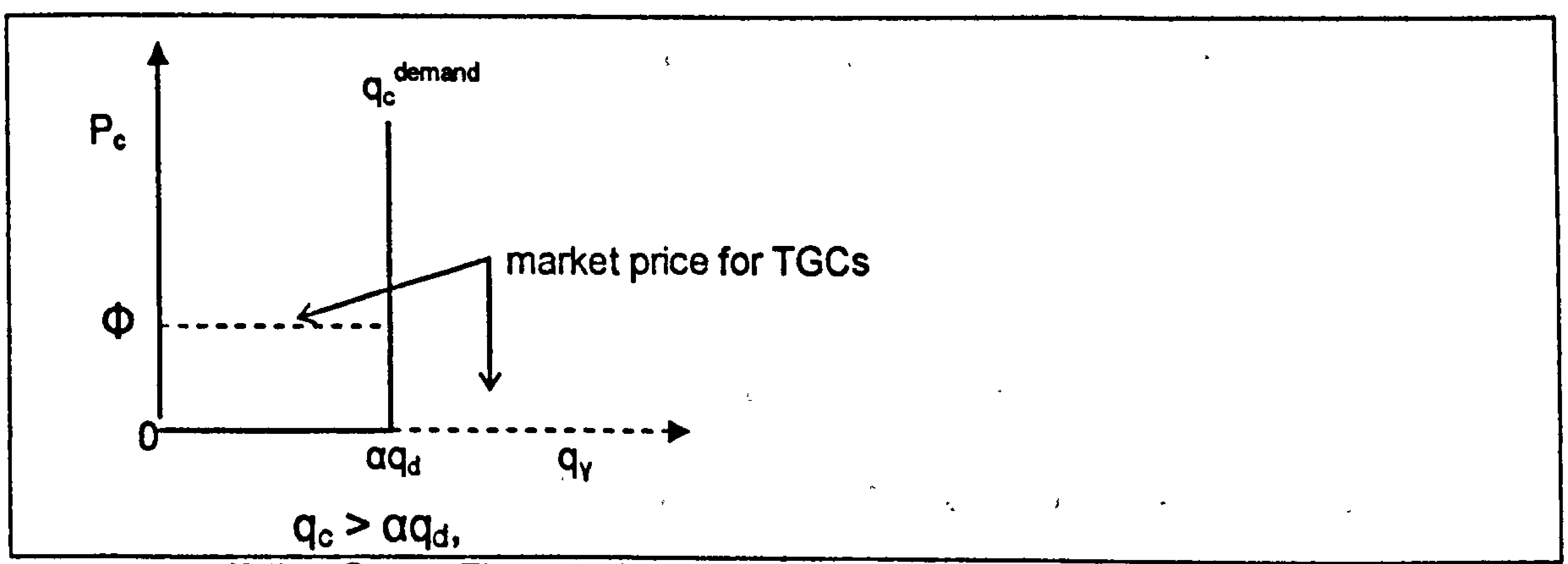
The Brown Firm will purchase and submit all TGCs and pay the buyout fee for the balance of the obligation not met with TGCs. (See diagram 6.2)

The green certificate price will be equal to zero for certificates in excess of the obligation required from the Brown Firm,

If $q_c > \alpha q_d$, than $P_c = 0$, for TGCs in excess of obligation (6.3)

The Green Firm will not sell green certificates below the buyout price, $\Phi$. It is assumed that the Brown Firm is not indifferent between purchasing green certificates and paying the buyout price, but has a weak preference to meet its renewables obligation by participating in the tradable green certificates market. Publicly appearing to support environmental programs and cooperating with government regulators could be a motivation for this weak preference.

<u>Diagram 6.3</u> **Market for Green Certificates with $q_c^{supply} > q_c^{demand}$**




If the Green Firm produces more TGCs than the Brown Firm (monopsonist) is obligated to submit to the State, the price will collapse to a price of zero after the obligation quantity is met. The market will not clear all TGCs.

No market exists for green certificates in excess of the mandated quantity to be submitted to the State. The dominant firm is a profit maximizer and will only incur the cost of green certificates to a point compliant with the statutory regulation.

> An aside:
>
> What if the Green Firm were a monopolist, or cartel of individuals acting as one entity, and not an aggregation of many small subordinate firms?
>
> In a monopolist-monopsonist market, the market equilibrium price is a negotiated value determined by the relative power of each player. In this TGC market the monopsonist (Brown Firm) is obligated to purchase certificates to meet the State's mandate. Therefore the monopsonist (Brown Firm) has relatively little or no power in negotiations with the monopolist (Green Firm). The monopolist (Green Firm) can demand a price from the monopsonist (Brown Firm) up to a level where all producer surpluses from the parallel power market is now captured by the monopolist (Green Firm). The buyout fee option allows the monopsonist (Brown Firm) to reject any price offer greater than the buyout fee, while the monopolist (Green Firm) will reject any price less than the buyout fee. All TGCs will be transacted because the monopsonist (Brown Firm) is assumed to have a weak preference to participate in the TGC market over the option of paying the buyout fee.

It is assumed that the existing capacity of the Green Firm at the start of any game is insufficient to produce all the TGCs required to match the Brown Firm's obligation. Green certificate supply will be less than the demand from the Brown Firm.

**Brown Firm (dominant, leader, non-renewable power generator)**

The Brown Firm is a profit maximizer with normal profit equation of Total Revenues - Total Costs. Total Revenue is a function of the quantity produced by the firm and market price. Total Cost is a function of quantity produced by each individual firm, quantity of TGCs, price of TGCs, the buyout fee and the quota level. The short run profit equation:

$$\Pi_d (q_d) = TR_d - TC_d = TR_d (q_d, P_e) - TC_d (q_d, q_r, q_c, P_c, \Phi, \alpha),$$
$$\text{subject to } q_d \geq 0.$$

(6.4)

$$TR_d = P_e(Q_e) * q_d : \text{short run revenue}$$

(6.5)

$$TC_d = ½\, q_d^2 + P_c{}^*q_c + \Phi * (\alpha q_d - q_c): \text{short run costs}$$

(6.6)

The short run total cost of $firm_d$ is composed of two categories, production cost of electricity and the cost of complying with the State's TGC obligation:

$$½\, q_d^2$$

(6.7)

- Variable cost of fossil fuelled power production

and

$$P_c{}^* q_c + \Phi * (\alpha q_d - q_c)$$

(6.8)

- Cost of compliance with renewables obligation. Total purchases of green certificates and payments of the buyout option to the State, if there is a shortfall in green certificates to meet the obligation.

The Brown Firm is a price taker for fuel purchased to produce electricity. The Brown Firm is a monopsonist in the market for TGCs, as it is the only player which gains utility from the good.

The Brown Firm is aware that its production decision influences the production decision of the Green Firm.

**Green Firm (subordinate, fringe, follower, renewable energy generator)**

The profit maximizing function for the Green Firm is that of a revenue maximizer, as it is assumed that no short run variable costs are incurred. Most renewable energy technology is based on taking diffuse energy available from the environment, e.g., wind, water, solar, and converting this "free" input into electricity. The profit equation is composed of two revenue sources: the sale of electricity, which is the market price for all power sold; and all TGCs that may be sold at the TGC market price.

$$\Pi_r (q_r) = TR_r = P_e(Q_e) * q_r + q_c * P_c \quad (6.9)$$

The Green Firm is a price taker in the market for electric power. However, the Green Firm acts in a competitive manner in the TGC market.

**Government**

The State has a policy objective to increase the amount of electric energy produced from renewable energy sources. This quantity objective is determined exogenously. To maximise the quantity of green power the State uses two policy tools, the value of the buyout fee and the obligation quota.

The State's objective function is:

$$\text{Max } q_r(\Phi,\alpha), \text{ subject to } P_e(Q_e) \leq \beta$$

(6.10)

Using policy variables, $\Phi$ and $\alpha$, the State desires to maximize the quantity of renewable power generated by the dominant firm, with a single constraint that the market price of electricity not exceed some price, $\beta$. $\beta$ is an ambiguous non-defined value that is determined exogenously to this game by the politics of the State. $\beta$ represents an increased price of electricity where the loss of consumer surplus is not a politically acceptable exchange for the expansion of renewable energy.

To support the revenue of the Green Firm, the TGC obligation is set by the State at a level higher than the production capacity of green certificates. This assures a market for TGCs and that the TGC price will be equal to the buyout fee. To facilitate the objective, it is assumed:

$$q_c < \alpha q_d$$

(6.11)

To insure grid security the Brown Firm is compelled to balance the market and meet demand, after accounting for the Green Firm's production decision. The Brown Firm is compelled to vary its production to allow the

Green Firm to fulfil its initial production decision. Therefore, market demand will always be equal to production by both Green and Brown Firms.

$$Q_e \equiv q_d + q_r$$

(6.12)

All relative parameters are known, by the State, Brown and Green in advance of each step.

Transparency of policy is important to the State so it functions to make all parameters public knowledge.

**Solving the Model**

In this section a solution is found for the model which has been describe above. A standard backwards induction procedure is used. The end goal of this procedure is to attain two equations. The first equation is the Green Firm's profit maximising equation as a function of the obligation quota and the buyout fee. The second equation is the market equilibrium price of electricity as a function of the same two variables, the obligation quota and the buyout fee.

With these two equations, the State's goal of maximising renewable energy production while assuring the price of electricity does not exceed a critical level can be represented as a constrained optimisation problem. This constrained optimisation problem can be solved using the Lagrangian method.

**Mathematics of Backward Induction**

**Step I.**

Green Firm (fringe-follower's reaction function)

The profit maximization equation of the renewable power producer (Green):

$\Pi_r \quad = TR_r - TC_r$ (6.13 a)

$= P_e q_r + P_Y q_Y - 0$ (6.13 b)

$= P_e q_r + P_Y q_Y$ (6.13 c)

$= [(a - b(Q_e))q_r] + P_Y q_Y$ (6.13 d)

$= [(a - b(q_d + q_r))q_r] + P_Y q_Y$ (6.13 e)

$= [(a - bq_d - bq_r)q_r] + P_Y q_r$ (6.13 f)

$= [aq_r - bq_d q_r - bq_r^2] + P_Y q_r$ (6.13 g)

$\Pi_r \quad = aq_r - bq_d q_r - bq_r^2 + P_Y q_r$ (6.13 h)

With substitution of $P_Y = \Phi$

$\boxed{\textbf{Firm's profit equation: } \Pi_r = aq_r - bq_d q_r - bq_r^2 + \Phi q_r}$ (6.13 i)

To solve for the reaction function of $Firm_r$:

F.O.C.: $\delta \Pi_r / \delta q_r = 0$ and $MR_r = MC_r$. (6.14 a)

$\delta \Pi_r / \delta q_r = 0 = a - bq_d - 2bq_r + \Phi$ (6.14 b)

$-a + bq_d + 2bq_r - \Phi = 0$

(6.14 c)

$2bq_r = a - bq_d + \Phi$ (6.14 d)

$q_r = (a - bq_d + \Phi)/ 2b$ (6.14 e)

$q_r = [(a + \Phi)/ 2b] - [bq_d/ 2b]$ (6.14 f)

$q_r^* \quad = [(a + \Phi)/ 2b] - ½\, q_d$ (6.14g)

$\boxed{\textbf{Green profit maximizing reaction function: } q_r^{max}(q_d, \Phi) = [(a + \Phi)/ 2b] - \tfrac{1}{2} q_d}$ (6.14 h)

**Step II.**

Brown Firm (leaders profit maximization function)

The profit maximization equation of the dominant power producer (leader):

The dominant firm's profit function is:

$$\Pi_d = TR_d - TC_d \quad (6.15\text{ a})$$
$$= P_e q_d - \tfrac{1}{2} q_d^2 - [P_c q_c + \Phi(\alpha q_d - q_c)] \quad (6.15\text{ b})$$
$$= [(a - b(Q_e))q_d] - \tfrac{1}{2} q_d^2 - [P_c q_c + \Phi\alpha q_d - \Phi q_c] \quad (6.15\text{ c})$$
$$= [(a - b(q_d + q_r))q_d] - \tfrac{1}{2} q_d^2 - [P_c q_c + \Phi\alpha q_d - \Phi q_c] \quad (6.15\text{ d})$$
$$= [(a - bq_d - bq_r)q_d] - \tfrac{1}{2} q_d^2 - [P_c q_c + \Phi\alpha q_d - \Phi q_c] \quad (6.15\text{ e})$$
$$= [aq_d - bq_d^2 - bq_r q_d] - \tfrac{1}{2} q_d^2 - [P_c q_r + \Phi\alpha q_d - \Phi q_c] \quad (6.15\text{ f})$$
$$= aq_d - bq_d^2 - bq_r q_d - \tfrac{1}{2} q_d^2 - P_c q_r - \Phi\alpha q_d + \Phi q_r \quad (6.15\text{ g})$$
$$= aq_d - bq_d^2 - \tfrac{1}{2} q_d^2 - \Phi\alpha q_d - bq_r q_d - P_c q_r + \Phi q_r \quad (6.15\text{ h})$$
$$= aq_d - bq_d^2 - \tfrac{1}{2} q_d^2 - \Phi\alpha q_d - [(q_r)^*(bq_d - P_c + \Phi)] \quad (6.15\text{ i})$$
$$\boxed{\Pi_d = aq_d - bq_d^2 - \tfrac{1}{2} q_d^2 - \Phi\alpha q_d - [(a - bq_d + \Phi)/ 2b)^*(bq_d - P_c + \Phi)]} \quad (6.15\text{ j})$$

With substitution of $P_c = \Phi$

$$\boxed{\Pi_d = aq_d - bq_d^2 - \tfrac{1}{2} q_d^2 - \Phi\alpha q_d - [(a - bq_d + \Phi)/ 2b)^*(bq_d)]}$$

(6.15 k)

To solve for $q_d^{max}$:

F.O.C.: $\delta \Pi_d / \delta q_d = 0$ and $MR_d = MC_d$. (6.16 a)

$$\delta \Pi_d / \delta q_d = 0 = a - 2bq_d - q_d - \Phi\alpha - [(-\tfrac{1}{2})bq_d + ((a - bq_d + \Phi)/ 2b)(b)] \quad (6.16\text{ b})$$
$$= a - 2bq_d - q_d - \Phi\alpha + \tfrac{1}{2} bq_d - ((a - bq_d + \Phi)/ 2) \quad (6.16\text{ c})$$
$$= a - 2bq_d - q_d - \Phi\alpha + \tfrac{1}{2} bq_d - \tfrac{1}{2} a + \tfrac{1}{2} bq_d - \tfrac{1}{2}\Phi \quad (6.16\text{ d})$$
$$= \tfrac{1}{2} a - bq_d - q_d - \Phi\alpha - \tfrac{1}{2}\Phi \quad (6.16\text{ e})$$

$$bq_d + q_d = ½ a - Φα - ½ Φ \quad (6.16\ f)$$

$$q_d (b + 1) = ½ a – Φα - ½ Φ \quad (6.16\ g)$$

$$q_d^{max} = (½ a - Φα - ½ Φ) / (b+1) \quad (6.16\ h)$$

Brown Firm's profit maximizing level of production:

$$\boxed{q_d^{max}(Φ,α) = (a - 2Φα - Φ) / 2(b+1)} \quad (6.16\ i)$$

**Step iii.**

Firm$_r$'s profit maximizing level of production given Firm$_d$'s output.

$$q_r^{max} = [(a + Φ)/ 2b] – ½ q_d \quad (6.17a)$$

$$= [(a + Φ)/ 2b] – [½ (a - 2Φα - Φ) / 2(b+1)] \quad (6.17b)$$

$$= [(a + Φ) / 2b] - [(a - 2Φα - Φ) / 4(b+1)] \quad (6.17c)$$

$$= [((2(b+1)/2(b+1))*((a + Φ) / 2b)] - [((b/b)*(a - 2Φα – Φ)) / 4(b+1)] \quad (6.17d)$$

$$= (2ab +2a +2bΦ + 2Φ - ab + 2bΦα + bΦ) / 4b(b+1) \quad (6.17e)$$

Fringe firm's profit maximizing level of production:

$$\boxed{q_r^{max}(Φ,α) = (ab +2a +3bΦ +2bΦα + 2Φ) / 4b(b+1)} \quad (6.17f)$$

**Step iv.**

Market equilibrium for production and price.

Total electricity production:

$$Q_e = q_d + q_r \quad (6.18)$$

$$Q_e = [(a - 2Φα - Φ) / 2(b+1)] + [(ab +2a +3bΦ +2bΦα + 2Φ) / 4b(b+1)] \quad (6.18a)$$

$$Q_e = [(a - 2Φα – Φ) / 2(b+1)] + [(ab +2a +3bΦ+2bΦα + 2Φ)/(4b(b+1))] \quad (6.18b)$$

$$\boxed{Q_e (Φ, α) = (3ab + 2a - 2bΦα + bΦ + 2Φ) / (4b(b+1))} \quad (6.18c)$$

Market price of electricity:

$$P_e(Q_e) = a - b(Q_e) \quad (6.18a)$$

$$P_e = a - b\,(3ab + 2a - 2b\Phi\alpha + b\Phi + 2\Phi) \,/\, (4b(b+1)) \quad (6.18b)$$

$$\boxed{P_e\,(\Phi, \alpha) = a - ((3ab + 2a - 2b\Phi\alpha + b\Phi + 2\Phi) \,/\, (4(b+1))} \quad (6.18c)$$

**Step v.**

Government Policy

The State's goal is to maximize the amount of renewable energy being produced while keeping electricity prices below a maximum acceptable level. Higher electricity prices lead to a lower level of consumer surplus which is politically undesirable.

The State's policy goal is expressed by maximising production by the Green Firm while being constrained by a market price of electricity, as shown in the following equation:

Max $q_r\,(\Phi,\alpha)$, subject to $P_e(Q_e) \leq \beta$,

From Step iii, above, the production functions of the Green Firm in terms of $\Phi$ and $\alpha$, the buyout fee and the obligation quotas:

$$q_r^{max}(\Phi,\alpha) = (ab + 2a + 3b\Phi + 2b\Phi\alpha + 2\Phi) \,/\, 4b(b+1)$$

From Step iv, above, the market price of electricity in terms of $\Phi$ and $\alpha$:

$$P_e\,(\Phi, \alpha) = a - ((3ab + 2a - 2b\Phi\alpha + b\Phi + 2\Phi) \,/\, (4(b+1))$$

The problem can be set up as a Lagrangian constrained optimization:

$$L = (ab + 2a + 3b\Phi + 2b\Phi\alpha + 2\Phi) / 4b(b+1)$$

$$+ \lambda[\beta - (a - ((3ab + 2a - 2b\Phi\alpha + b\Phi + 2\Phi) / (4(b+1)))]$$

However, this equation cannot be solved algebraically.

**Comparative Statics Analysis**

The ambition of this chapter is to understand how the obligation quota and the buyout fee interact with the price of electricity. Given the Lagrangian constrained optimisation equation does not have a unique solution, but is ambiguous, the State's policy variables can be analyzed in comparative statics framework.

Comparative statics is a method by which we can determine the effect model variables have on the two key policy variables. Static analysis indicates how the equilibrium value of an endogenous variable will change when there is a change in any of the exogenous variables or parameters.

Consumer surplus is inversely related to the price of electricity. To determine the change in consumer surplus it is necessary to examine how the variables $\Phi$ and $\alpha$, obligation quota and buyout fee, interact with $P_e$.

Affect of $\Phi$ on $P_e$

$$P_e = a - ((3ab + 2a - 2b\Phi\alpha + b\Phi + 2\Phi) / (4(b+1))$$

$$\delta P_e / \delta \Phi = (2b\alpha - b - 2) / (4(b+1))$$

For $0 \leq \alpha \leq .5$; $\delta P_e / \delta \Phi < 0$

For $.5 < \alpha$; the sign of $\delta P_e / \delta \Phi$ is dependent on the value of b, the slope coefficient for the market demand for electricity. (See Note-2) and

Affect of $\alpha$ on $P_e$.

$P_e = a - ((3ab + 2a - 2b\Phi\alpha + 3b\Phi + 2\Phi) / (4(b+1))$

$\delta P_e / \delta \alpha = (2b\Phi) / (4(b+1))$

Since $\Phi \geq 0$; $\delta P_e / \delta \alpha \geq 0$

**Table 6.1 Comparative Statics Analysis of Short-run Stackelberg Equilibrium**

| | $Q_e$ | $P_e$ | $q_d^*$ | $q_r^*$ | $\pi_d$ | $\pi_r$ | *Consumer Surplus* |
|---|---|---|---|---|---|---|---|
| $\Phi$ | + | ? | - | + | - | + | ? |
| $\alpha$ | - | + | - | + | - | 0 | - |

Effect on electricity prices:
- + indicates the interacting variables increase price;
- - indicates the interacting variables decrease price;
- ? indicates ambiguous results (the effect is either indeterminate or the sign changes value at some critical level).

This matrix of indicates how State policy variables, obligation quota and buyout fee, $\Phi$ and $\alpha$, interact with the two Stackelberg firms to determine equilibrium price and quantity of the electricity market. For a complete demonstration of how these interactions were derived see section – Notes 1 at end of this chapter.

The results can be summarized:

1. The buyout fee, $\Phi$, is ambiguous in its effect on $P_e$. The influence of the buyout fee, $\Phi$, is dependent on the values of the obligation quota, $\alpha$, and on the slope parameter, b, of the linear demand equation. There are some combinations of $\alpha$ >.5 and b, that the derivative, $\delta P_e / \delta \Phi$ will be positive. (See Graph 4.3)

2. $P_e$, the market price of electricity increases as the obligation quota, $\alpha$, increases, as long as the buyout fee, $\Phi$, is > 0.

**Ad Hoc Evaluation**

To further investigate the two policy variables to be examined this chapter conducts an ad hoc analysis. Ad hoc values are hoped to give insight and relevance to how actual institutions will function. An electricity market demand equation is used to further evaluate the effects of government policy. Using a simplified linear demand equation where, a, is the intercept and, b, is the slope parameter, and all other variables are as previously described, gives a market equation:

$$P_e(\Phi, \alpha) = a - ((3ab + 2a - 2b\Phi\alpha + b\Phi + 2\Phi) / (4(b+1))$$

(17c)

Inputting the values a = 75 and b =9 (See Note-3 for the how these ad hoc values were derived); the equation can be reduced from four unknowns to two unknowns, $\Phi$ and $\alpha$, the buyout fee and obligation quota.

$P_e(\Phi, \alpha) = 75 - ((3*(75)*(9) + 2(75) - 2*(9)*\Phi\alpha + (9)*\Phi + 2\Phi)$ / $(4(9+1))$, can be simplified to:

$P_e(\Phi, \alpha) = 75 - ((2175 - 18\Phi\alpha + 9\Phi + 2\Phi) / (40))$,

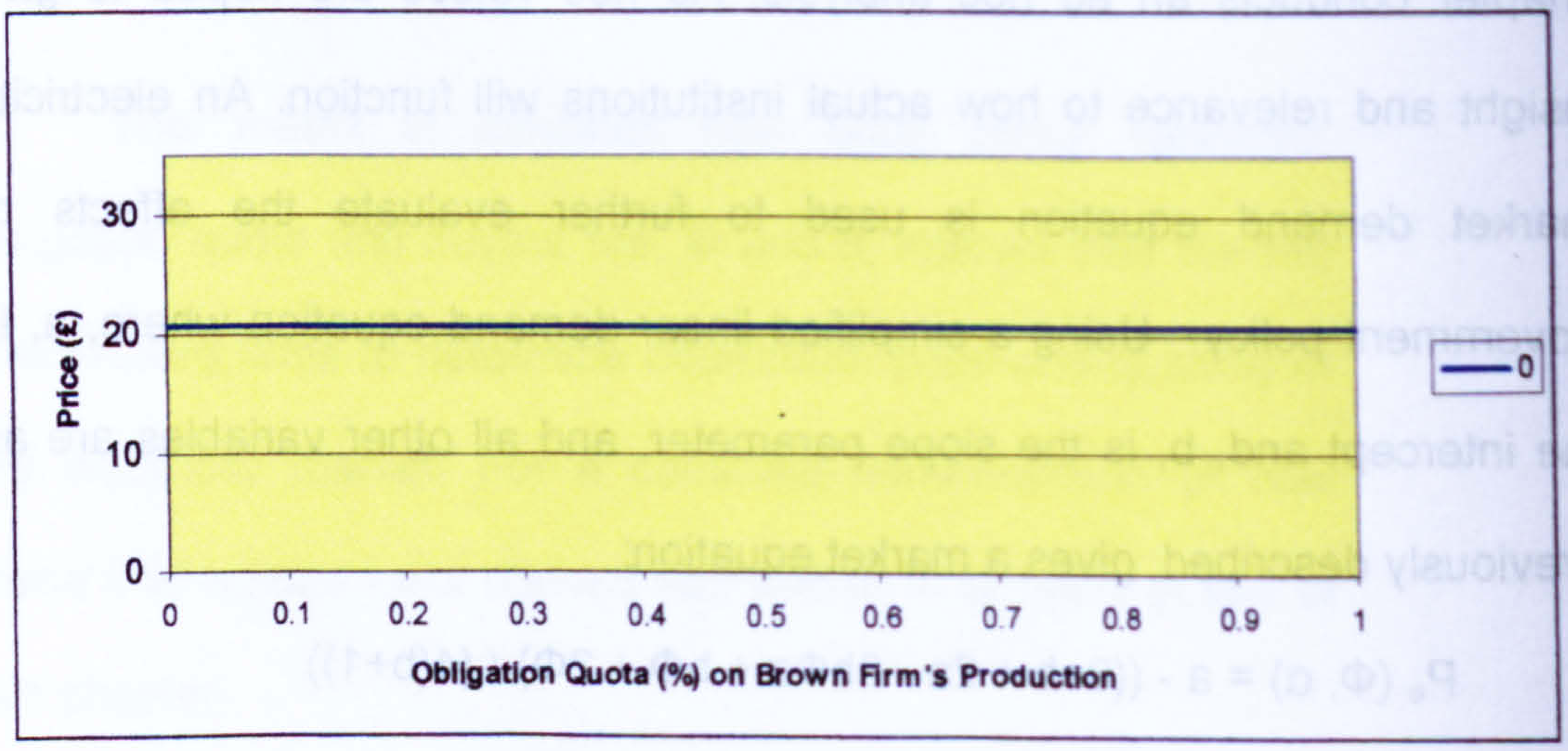
$P_e(\Phi, \alpha) = 20.625 - ((-18\Phi\alpha + 11\Phi) / (40))$

From the above equation, it can know be shown:

If $\Phi$ is zero, the equivalent of no TGC program, than $P_e$ = 20.625, which equals the normal Stackelberg game equilibrium with a single market. See

Graph 6.1 below.

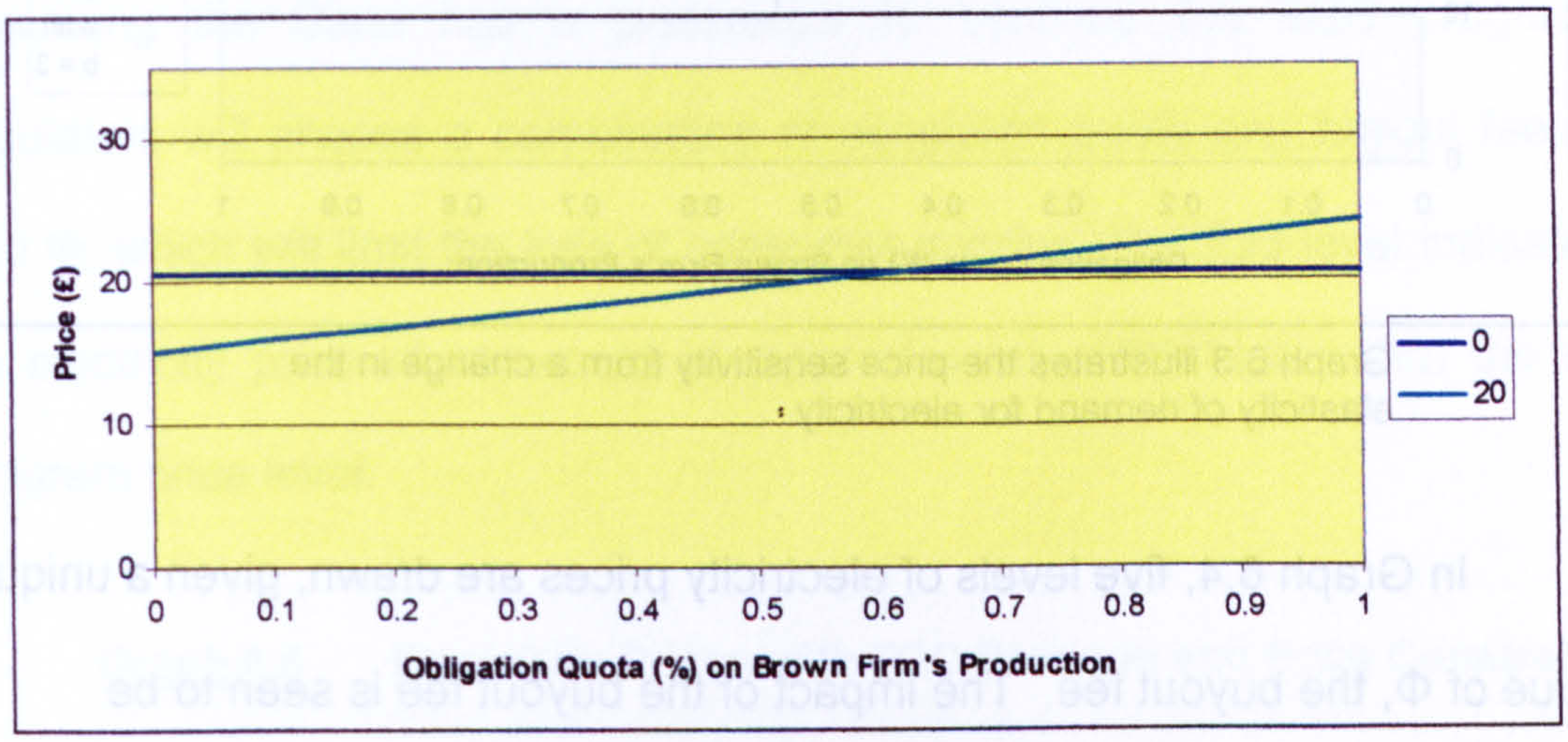
**Graph 6.1** **Equilibrium Price with No TGC Program**




Graph 6.1 shows the price of electricity when there is not active TGC market, with a buy out fee set at zero (see legend). The price is £20.625, the status quo or no TGC program value.

When the buyout fee is greater than 0, a unique $P_e$ exists for any specific value of the obligation quota. In Graph 6.2, below, the government's buyout price is set at £20. It demonstrates that the price reducing effect of the buyout fee, $\delta P_e / \delta \Phi < 0$, dominates the price increasing effect of the obligation quota, $\delta P_e / \delta \alpha \geq 0$, and $P_e$ is below the normal Stackelberg equilibrium, until $\alpha > .6111$, at which point $\delta P_e / \delta \Phi > 0$, and the TGC market manifests a net increase in electric prices. (See Notes-2)

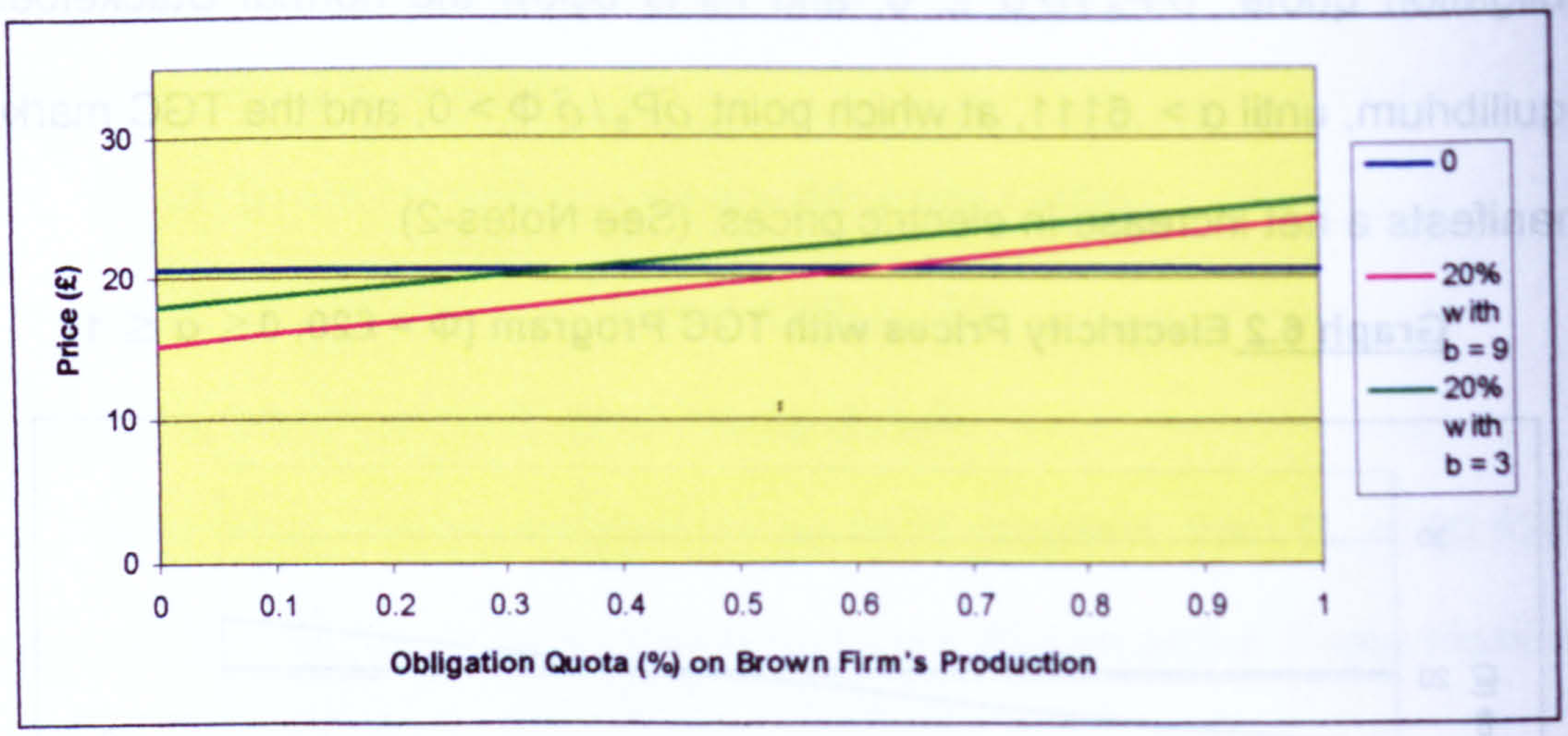
**Graph 6.2 Electricity Prices with TGC Program ($\Phi$ = £20, $0 \leq \alpha \leq 1$)**




Graph 6.2 shows that a positive buyout fee, £20, relative to the status quo level, £0, results in lower electricity prices below a critical obligation quota, but increases price over a certain quota.

To test the sensitivity of the elasticity of demand for electricity the linear slope is changed in the equation. In Graph 6.3, below, the effects of a downward change in the demand slope coefficient are demonstrated. The transition of $\delta P_e / \delta \Phi < 0$ to $\delta P_e / \delta \Phi > 0$ occurs at distinct values of $\alpha$, as b increases. It can be inferred that the elasticity of demand for electricity is significant to determining the level of TGC obligation that results in electric price increases. The more inelastic the demand, the higher the level of $\alpha$ can be set before $\Phi$ will lead to a price increase.

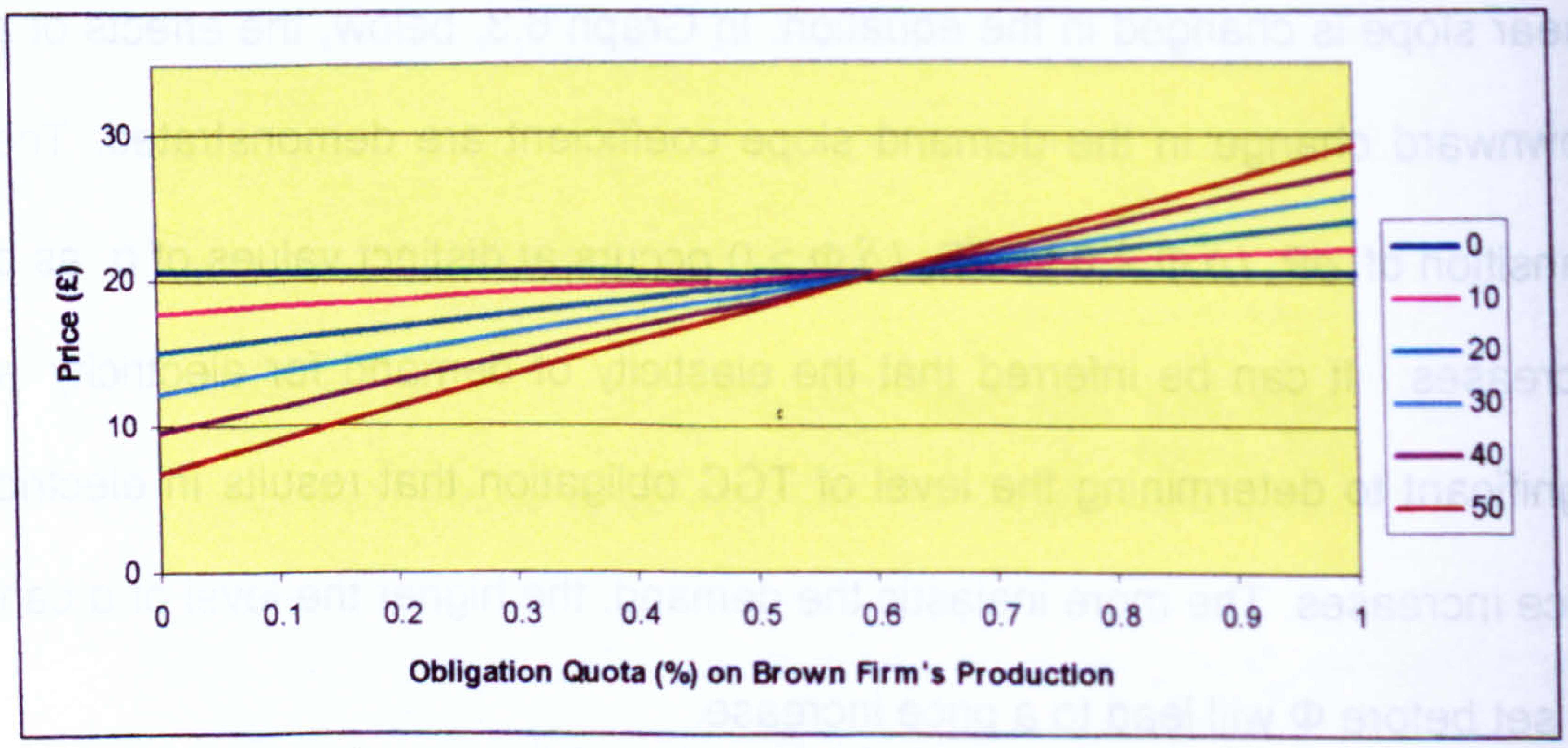
**<u>Graph 6.3</u>** **Electricity Prices with TGC Program (Change in slope parameter)**




Graph 6.3 illustrates the price sensitivity from a change in the elasticity of demand for electricity.

In Graph 6.4, five levels of electricity prices are drawn, given a unique value of Φ, the buyout fee. The impact of the buyout fee is seen to be proportional to the level, the greater the buyout fee, the lower the price of power at low quotas and the higher the price of power at high quotas

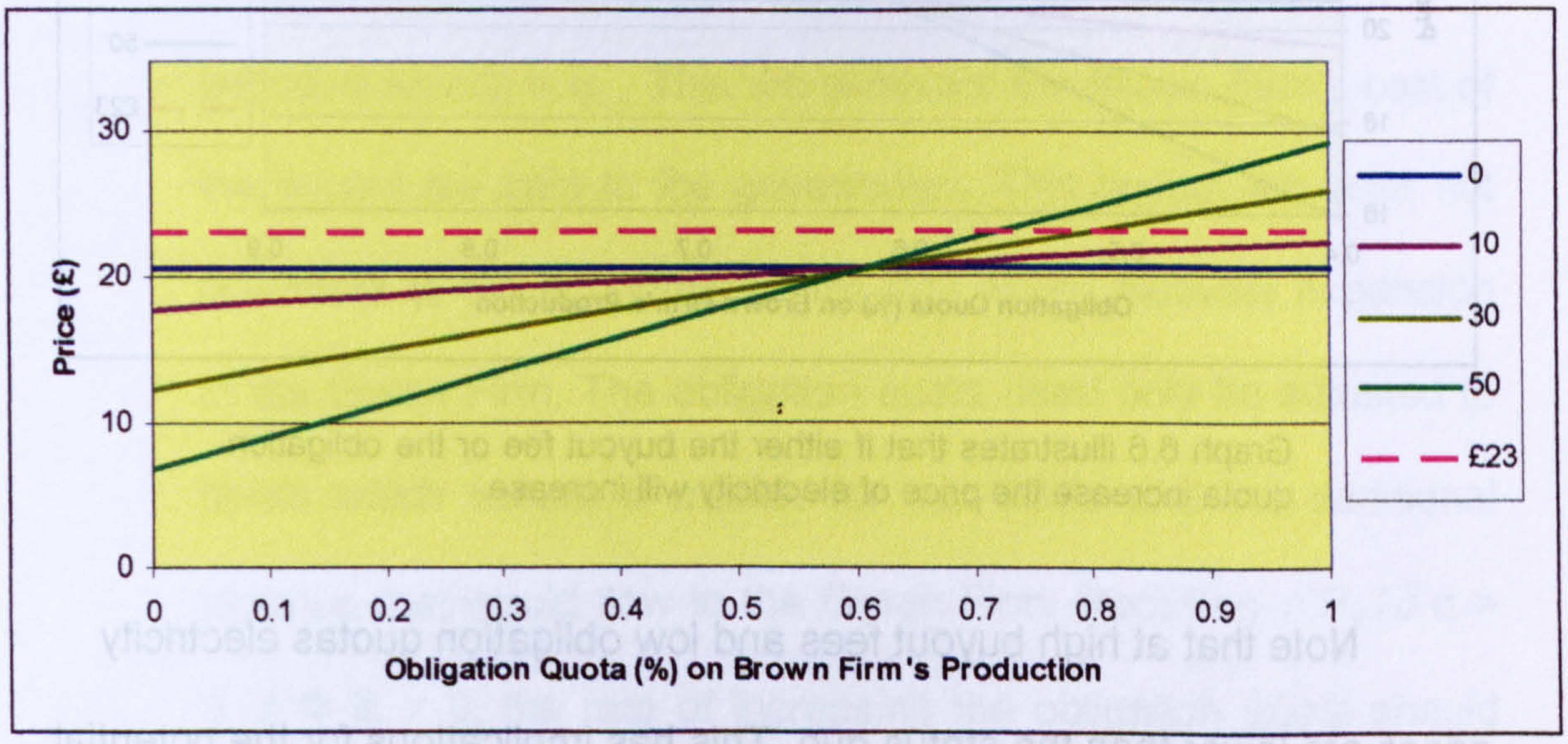
**<u>Graph 6.4</u>** **Electricity Prices with TGC Program (Multiple Values of Φ)**




Graph 6.4 shows the impact of different buyout fees on the price of electricity, given the level of obligation quota.

In Graph 6.5, $\beta$ is now included. $\beta$ is a politically detemined price constraint. Any new equilibrium price above the normal Stackelberg price must be less than $\beta$. If this price constraint is violated, the desired benefits of increasing renewable energy by use of the TGC program is deemed to be political unacceptable to the State because of the loss of consumer surplus. Assuming the State has a preference to continue the TGC program, regulators will choose a combination of obligation quota and buyout fee, $\alpha$ and $\Phi$, which will limit the loss of consumer surplus. The £23 level indicates an electricity price which would be approximately 10% higher that the no program price level.

**Graph 6.5** **Electricity Prices with TGC Program and Price Constraint**




Graph 6.5 shows the effect of different buyout fees on the price of electricity for any level of obligation quota.

Graph 6.6, below is an enlargement of Graph 6.5, allows for visual inspection to show that either the buyout fee or the obligation quota variables, $\Phi$ or $\alpha$, or the political variable, unacceptable electricity price, $\beta$, can be endogenously determined if two of the three variables are predetermined.

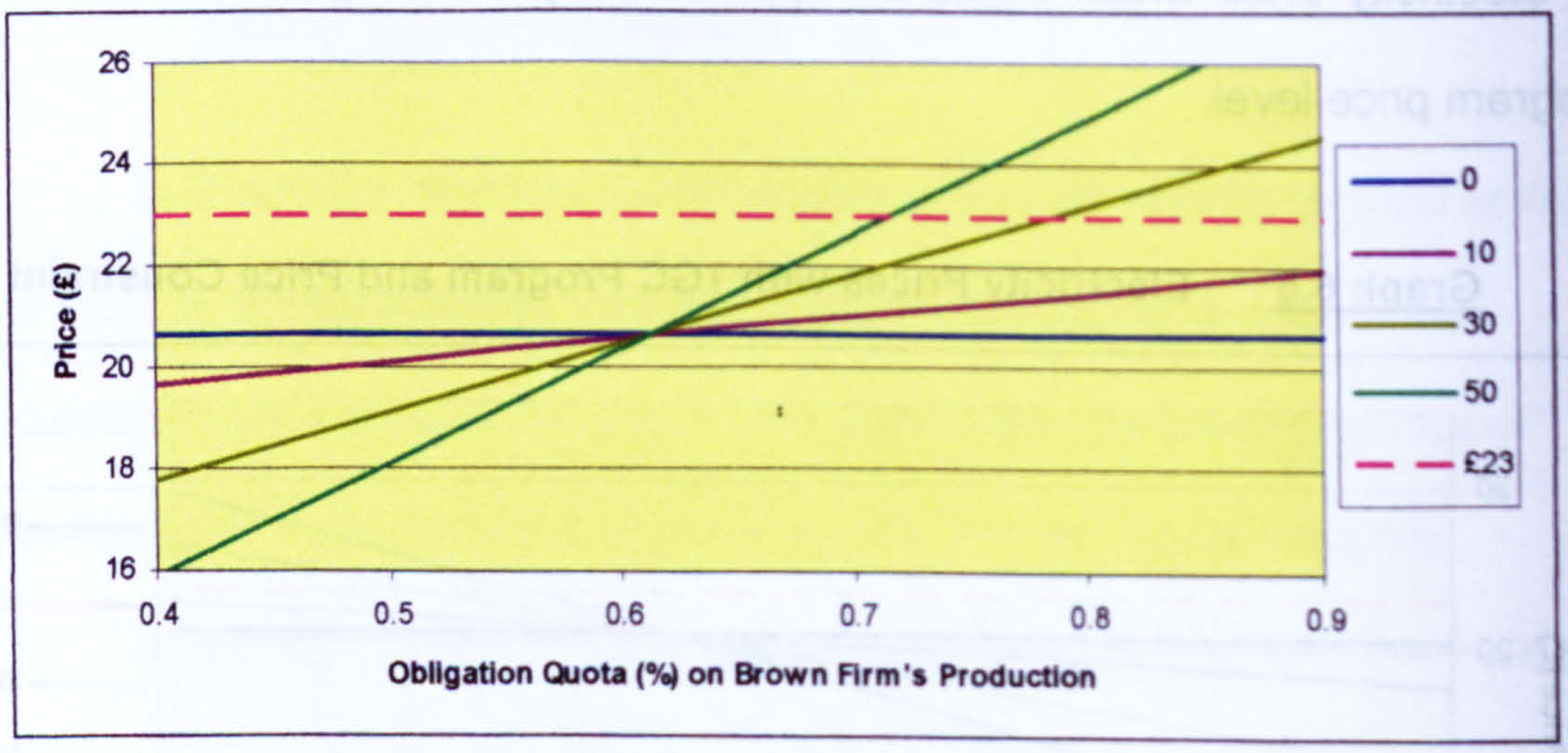
Taking the equation:

$P_e(\Phi, \alpha) = 20.625 - ((-18\Phi\alpha + 11\Phi) / (40))$

and substituting in $\beta$ for $P_e$,

$\beta = 20.625 - ((-18\Phi\alpha + 11\Phi) / (40))$, given any two of the variables, the third is determined.

**Graph 6.6 Electricity Prices with TGC Program and Price Constraint (enlarged Graph 4.5)**




Graph 6.6 illustrates that if either the buyout fee or the obligation quota increase the price of electricity will increase.

Note that at high buyout fees and low obligation quotas electricity prices are lower than the status quo. This has implications for the potential use of feed-in-tariffs, instead of TGC markets.

**Conclusion**

There is no unique equilibrium for this modified Stackelberg game. There are a quasi-infinite number of combinations of TGC obligations ($\alpha$) and buyout payment values ($\Phi$) that the State could chose. However, the two electric power firms, Green and Brown, do have sub-game perfect equilibrium games once the State has determined its optimal policy for the TGC program.

There are general optimizations procedures that the government could follow if it desires to minimize the increased cost of electricity, yet expand renewables generation. They are:

1. Set the obligation quota at a level where the quantity of TGCs is closer to the quantity demand from the Brown Firm in any one period, $\alpha$ so $\alpha q_d = q_c$. This will eliminate the Brown Firm's cost of the buyout fee paid to the government. This buyout fee does not contribute to the economic profits that would motivate expansion of the Green Firm. The obligation quota need only be adjusted to levels which assure a market for the TGCs and the additional revenue that would flow to the Green Firm. Recalling $\delta P_e / \delta \alpha >$ 0, if $\Phi$ is > 0, the rate of increasing the obligation quota should only be as fast as the Green Firm could expand.
2. Policy decision should be aware that more inelastic the demand for power, the higher the obligations quota can be set before the buyout fee leads to a price increase.

3. Set the buyout fee at a level which creates economic incentives for the Green Firm to expand.

This last point illuminates one of the weaknesses of this model and brings into focus the primary purpose of TGC programs. Why does a renewable energy firm need additional revenues to motivate expansion given the reasonably accurate assumption that the firm has no marginal cost of production?

The cost structure of the Green Firm is totally comprised of a large fixed cost of capital financing. The shutdown decision for a firm in this form is:

If $P_e$ < AFC (average fixed cost of production), then exit market.

The object of the TGC market is to assure that $P_e + P_c \geq$ AFC. The State should set the buyout fee in item 2 above so this condition is met.

**Notes**

**Note – 1**

Comparative Static Analysis

<u>*Comparative static analysis of short run Stackelberg equilibrium*</u>

| | $Q_e$ | $P_e$ | $q_d^*$ | $q_r^*$ | $\pi_d$ | $\pi_r$ | Consumer Surplus |
|---|---|---|---|---|---|---|---|
| $\Phi$ | + | - | ? | + | - | 0 | ? |
| $\alpha$ | - | + | - | + | - | 0 | - |

$\alpha$ is conditional on $\Phi$ >0, except for $\pi_r$.

<u>Interactions</u> <u>Relationship</u>

## Affect of $\Phi$ and $\alpha$ on $Q_e$.

$Q_e(\Phi, \alpha) = (3ab + 2a - 2b\Phi\alpha + 3b\Phi + 2\Phi) / (4b(b+1))$

$\delta Q_e / \delta \Phi = (-2b\alpha + 3b + 2) / (4b(b+1))$

Since $0 \leq \alpha \leq 1$; $\delta Q_e / \delta \Phi > 0$

Total electricity production moves with the direction of change in the buyout price.

Individual firm's reaction: For an increase in $\Phi$, the increase in $Firm_r$'s electricity production is greater than the reduction in $Firm_d$'s production.

$Q_e(\Phi, \alpha) = (3ab + 2a - 2b\Phi\alpha + 3b\Phi + 2\Phi) / (4b(b+1))$

$\delta Q_e / \delta \alpha = (-\Phi) / (2(b+1))$

Since $\Phi \geq 0$; $\delta Q_e / \delta \alpha \leq 0$

Total electricity production moves in the inverse direction as a change in the matching percentage of the renewables obligation.

Individual firm's reaction: For an increase in $\alpha$, the increase in $Firm_r$'s electricity production is less than the reduction in $Firm_d$'s production.

Affect of $\Phi$ and $\alpha$ on $P_e$.

$P_e = a - ((3ab + 2a - 2b\Phi\alpha + 3b\Phi + 2\Phi) / (4(b+1))$

$\delta P_e / \delta \Phi = (2b\alpha - 3b - 2) / (4(b+1))$

Since $0 \leq \alpha \leq 1$; **$\delta Q_e / \delta \Phi = ?$**

$P_e = a - ((3ab + 2a - 2b\Phi\alpha + 3b\Phi + 2\Phi) / (4(b+1))$

$\delta P_e / \delta \alpha = (2b\Phi) / (4(b+1))$

Since $\Phi \geq 0$; **$\delta Q_e / \delta \alpha \geq 0$**

The effect on market price of electricity is set by a deterministic equation, the assumed inverse demand function. Price moves in an inverse relationship to the quantity of electricity produced. The relationship of the policy variables to the change in price is as expected given the relationship of the policy variables to the total quantity produced.

Affect of $\Phi$ and $\alpha$ on $q_d$.

$q_d^{max}(\Phi,\alpha) = (a - 2\Phi\alpha - \Phi) / 2(b+1)$

$\delta q_d / \delta \Phi = (-2\alpha - 1) / 2(b+1)$

Since $0 \leq \alpha \leq 1$; **$\delta q_d / \delta \Phi < 0$**

$q_d^{max}(\Phi,\alpha) = (a - 2\Phi\alpha - \Phi) / 2(b+1)$

$\delta q_d / \delta \alpha = (-2\Phi) / 2(b+1)$

Since $\Phi \geq 0$; **$\delta q_d / \delta \alpha < 0$**

Affect of $\Phi$ and $\alpha$ on $q_r$.

$q_r^{max}(\Phi,\alpha) = (ab + 2a + 5b\Phi + 2\Phi + 2b\Phi\alpha) / 4b(b+1)$

$\delta q_r / \delta \Phi = (5b + 2 + 2b\alpha) / 4b(b+1)$

Since $0 \leq \alpha \leq 1$; **$\delta q_r / \delta \Phi > 0$**

$q_r^{max}(\Phi,\alpha) = (ab + 2a + 5b\Phi + 2\Phi + 2b\Phi\alpha) / 4b(b+1)$

$\delta q_r / \delta \alpha = (2b\Phi) / 2(b+1)$

Since $\Phi \geq 0$; $\delta q_r / \delta \alpha \geq 0$

Affect of $\Phi$ and $\alpha$ on $\Pi_d$.

$\Pi_d = aq_d - bq_d^2 - ½ q_d^2 - \Phi\alpha q_d - [(a - bq_d + \Phi)/ 2b)*(bq_d)]$

$\delta \Pi_d/\delta\Phi = -q_d ((\alpha+(½))$

Since $0 \leq \alpha \leq 1$; $\delta \Pi_d/\delta\Phi < 0$

$\Pi_d = aq_d - bq_d^2 - ½ q_d^2 - \Phi\alpha q_d - [(a - bq_d + \Phi)/ 2b)*(bq_d)]$

$\delta \Pi_d/\delta\alpha = -\Phi q_d$

Since $\Phi \geq 0$; $\delta \Pi_d/\delta\alpha \leq 0$

Affect of $\Phi$ and $\alpha$ on $\Pi_r$.

$\Pi_r = aq_r - bq_d q_r - bq_r^2 + \Phi q_r$

$\delta \Pi_r/\delta\Phi = +q_r$

Since $q_r \geq 0$; $\delta \Pi_d/\delta\Phi \geq 0$

$\Pi_r = aq_r - bq_d q_r - bq_r^2 + \Phi q_r$

$\delta \Pi_d/\delta\alpha = 0$

$\delta \Pi_d/\delta\alpha = 0$

**$\Phi \Rightarrow$ consumer surplus (?)**

**$\alpha \Rightarrow$ consumer surplus (-)**

The changes in consumer surplus which occur as a result of the policy variables being investigated move in a manner consistent with economic theory, as shown in $P_e$ and $Q_e$ above.

**Note - 2**

Given $\delta P_e / \delta \Phi = (2b\alpha - b - 2) / (4(b+1))$
and b = 9:

$\delta P_e / \delta \Phi = (2*(9)*\alpha - (9) - 2) / (4(9+1))$
$= (18\alpha - 11)/ (40)$
setting $(18\alpha - 11)/(40) = 0$;
it is found that $\delta P_e / \delta \Phi < 0$
if $\alpha < 0.6111$.

The pivot point, where $\delta P_e / \delta \Phi < 0$ transitions $\delta P_e / \delta \Phi > 0$, is determined by b, the slope coefficient of the electricity demand equation.

**Note – 3**

The values a = 75 and b = 9 satisfy the normal demand equation, P = a – b*Q, when substituting in the approximate Scottish values of P = £25/MWh and Q = 5.5 MWh/annum

# Chapter 7

## Conclusion

**Chapter Sections**

Review of Research and Findings

Policy Issues

**Review of Research and Findings**

Scotland is entering a transition period for its environment and economy as it decides which path to follow to meet its energy and power needs for the next fifty years. The electric power infrastructure needs major upgrading and new investment if Scotland is to maintain a secure and reliable electric power system to promote economic growth and quality of life for its population. Slightly less than one-third of the generating capacity within Scotland will be decommissioned in the next seven years and an additional 40% will be closed in 20 years. New traditional power plants, coal-fired or nuclear powered, are expected to take 10 to 15 years to complete once the decision to build is made, longer if litigation occurs. This essential investment will amount to tens of billions of Pounds by 2025.

Which technology should be used to replace current power generation facilities is the single most important decision that needs to be made. Most all other aspects of the power system will be determined once the source of power is known.

The Scottish Executive announced an aspiration to increase renewable sources for electric power to 40% by the year 2020 from a level of approximately 11% in 2004 (9% coming from hydro and 2% from other renewables). This is one of the most ambitious goals for any country in Europe, given Scotland has already developed its hydroelectric resources and only one or two major hydro schemes are even contemplated for the future. Most all of the renewables growth will have to come from new sources through the use of new or improved renewables technologies like wind farms, biomass generation, marine tidal and wave systems or landfill gas and other technologies.

This aspiration for greater use of renewables has been driven by the economic development opportunities that Scotland may be able to capitalize on and exogenous decisions by the United Nations and European Commission to reduce global greenhouse gas emissions.

Renewable sources of power have started to grow quickly in the past four years. Between 2000 and 2002 non-hydro sources of power over doubled, but were still insignificant at just 1.3% of production. A government program to promote deployment of renewables during 1990's was met with very limited success.

A new program was initiated in early 2002 that provided a combination of demand push-supply pull incentives. The Renewables Order (Scotland) required retail energy supplier to produce themselves or purchase a quota of tradable green energy certificates to submit to the government. This program has allowed renewables generating firms to increase revenues over 300% with the same level of energy produced. Since the inception of ROS there has been a 160% growth in renewables generating capacity and the potential for a 23-fold increase over the next five to seven years, if all currently considered projects come to completion.

There is potential for major harm to the environment and quality of life for people who will be impacted by this extraordinary expansion of renewables projects. There is a special concern as greater than 90% of the new capacity being considered by energy developers is proposed onshore wind farms.

Examining the social welfare issues around this expansion was the goal of Chapter 4. By asking the question, "Why are some types of renewable energy preferred over other types?" it was hoped that improved decisions could be made about the types of renewables development that should be promoted. Quantifying, in monetary terms, the positive and negative environmental impacts is one step in this process.

Since there are no commercial markets for environmental attributes of renewables projects, a stated preference method needed to be used. The choice experiment method was decided upon because of the need to compare distinct qualities of various types of renewables projects. A contingent valuation method would not have derived the underlying characteristic values that were desired for comparing distinctly different hypothetical energy projects.

After conducting focus groups, researching academic literature, governmental policy statements and press releases, as well as the popular press, four attributes were identified for use in the choice experiment along with a monetary attribute. The non-monetary attributes are impacts on landscape and wildlife, air pollution, and jobs creation; the monetary attribute was charges in annual electricity billings.

A representative population of Scottish households was desired for the choice experiment, so the electoral register was used to create a mailing list that represented all areas of Scotland. Approximately 550 registered Scottish citizens were mailed a survey packet containing the survey along with a cover letter explaining the choice experiment. The response rate from the mail out was over 40% and supplied in excess of 800 choice set answer.

Unfortunately, the sample population had statistically significant differences from the Scottish population. Two population characteristics in particular were different. The sample population had an income level below that of the general population and the sample population was more rural that the average of the national population. These characteristics are related as rural populations traditionally suffer from lower wages and lower annual earnings. It was hypothesized that the higher response rate from the rural population occurred because they are the population most likely to experience the energy projects, in both a positive and negative manner.

The survey consisted of several parts: an introduction described the Scottish Executive's pursuit of expansion for renewable energy projects, a description of the types of renewables under consideration, a discussion of the attributes under consideration, an explanation of the choice sets, presentation of four choice sets, and than collection of socio-economic information on the respondent.

Using random parameter logit regression analysis, estimated coefficients were derived for the indirect utility function. For each of the attributes and the various levels within each, the coefficients represent the influence on probability of choice. In an expanded model, which included socio-economic variables, two characteristics were identified that increased the preference for renewables. If the respondent was under the age of 40 years or if the respondent had a higher education they had a greater preference for renewables.

The resulting implicit prices from the expanded model analysis showed that the sample population was willing-to-pay £13.13 per household per annum to change energy projects from high impact on the landscape to no impact on the landscape. Sample households were not willing-to-pay for a reduction to low or moderate landscape impacts.

For wildlife, the sample households would be willing-to-pay £4.24 per household per annum to reduce slight harm to wildlife to no harm from potential projects. The sample group was willing-to-pay £15.89 per household per annum for actually improving wildlife from creating slight harm to wildlife,

And for having renewable energy projects that have no increase in air pollution instead of slightly increasing airborne pollution, the respondents were willing-to-pay £13.84 per household per annum.

These values met the scope criteria that higher WTP values should be observed for higher quality environmental goods that provide greater utility to the survey respondent.

Jobs creation proved to be statistically insignificant. While the coefficient for the monetary attribute was negative. This monetary coefficient matched standard economic theory. Overall explanatory power of the RPL was high with a McFadden Pseudo-$R^2$ value of 0.47. This is equivalent to an adjusted $R^2$ for an OLS regression of over 0.90. One derogatory finding for the MNL analysis was that the IIA assumption did not hold and heterogeneous preferences were indicated.

The high response rate from the rural population of Scotland and the supposition that this group would be more affected by the potential renewables development motivated a hypothesis that respondent's local could be a source of heterogeneous preferences. Segregating the sample population into rural and urban groups based on self-disclosed information. A log likelihood test confirmed that the two models proved to have greater explanatory power than the single full sample set, so the hypothesis was validated.

New implicit prices derived for the urban group changed moderately from the full sample set, but did not indicate any substantial re-interpretation of the results was necessary.

The implicit prices derived for the rural sub-sample did support a new and different interpretation from both the full sample set and the urban sub-group regression results. The rural sample no longer showed willingness-to-pay for any reduction of harm to the landscape. For wildlife the rural group would not pay for reducing slight harm from energy projects to no harm, but they would be willing-to-pay for a slight improvement in wildlife. A WTP to avoid any increase in air pollution continued to hold true for all three sample sets. But the rural sub-set WTP was now one-third higher than the full sample group and over 70% higher than the amount derived for the urban sub-sample.

Finally, employment became highly statistically significant for the rural group while it remained of no significance to the urban group. Combining this change of value, with other changes found for the rural respondents, it was inferred that the rural population was willing to allow some level of negative environmental impacts on their surroundings for the possibility of jobs creation and economic development. Rural populations in general would be willing-to-pay to reduce environmental impacts from being highly negative or pay if an actual improvement to the environment could result, but not for complete avoidance of impact.

Another hypothesis was proposed that income could be a source of heterogeneous preferences because economic literature and theory support the proposition that improved environmental quality is a luxury good. Persons with lower incomes would be expected to demonstrate an unwilling to pay for avoiding the negative impacts. This hypothesis was tested and rejected.

Finally, different scenarios of renewable energy projects were created and the social welfare changes calculated as estimated from the full sample group implicit prices. Large onshore wind farms were shown to be so adverse to the population that no WTP exists. Large offshore wind farms were the most highly valued and households would be willing-to-pay £31.88 per annum for their attributes.

Some weaknesses of this choice experiment have become apparent since its completion. None of the weaknesses cause the essential WTP findings to become suspect or invalid, but rather would have made the research stronger or more relevant to the literature on environmental valuation and hopefully to governmental policy makers.

Instead of pursuing estimated values of generic attributes of renewable energy projects, examining wind farms attributes specifically would have made the research more relevant and meaningful at this time. Wind farms are the dominant type of renewable energy projects being proposed and the public's awareness of them is very high. There is the possibility that respondents may have had difficulty thinking in generic attribute terms and not in wind farm attribute terms when making their choice selections.

A noise from energy projects attribute was not included in the experiment, but numerous persons have asked why it was not included. The popular press's continual mentioning of that attribute as a criticism of wind farms specifically, and major energy developments in general, has made it an issue of interest. No empirical research was found showing there is a real environmental change in noise levels from wind farms. Put more simply, no decibel-meter readings have been reported to believe this is a real environmental issue. It appears to be unsupported rhetoric, beyond on anecdotal stories. Also, the issue of noise was not mentioned in the focus groups.

The validity test, voting for the single most import attribute, was a good tool and demonstrated there was partial internal consistency in responses from the sample population. Presenting a list of various types of renewable energy projects, similar to project profiles used in the social welfare change analysis that was calculated, could have given a higher level of validity testing. Would the summed implicit prices for hypothetical projects have shown the same ordinal rankings as voting for preferred projects?

The attribute levels for landscape impacts might have benefited from more precise anchoring of the terms: low, moderate and high. A written definition of what moderate landscape impact means would have helped create conceptual consistency between respondents.

A strategic model of interactions between firms that generate and sell electric power and a government was presented. A government requirement motivated the creation of a new market for tradable green certificates to promote increased renewable energy production. Power economics literature has ignored the use of a Stackelberg model when conducting analysis of green certificate markets and trading to date.

A more accurate model of how existing power markets operate in much of the world is a scenario when one dominant player is able to exercise some level of market control and a competitive-fringe of small renewable energy firms exists. Understanding how the two principal policy tools used by the government interact in the electric power market is important to optimizing social welfare.

The first policy tool is the obligation level of green certificates that must be purchased by the dominant power firm and submitted to the government. The dominant firm is a strictly non-green producer of power. The second policy tool is the option price, or the buy-out price, that the dominant firm must pay if it chooses not to submit TGCs. Alone these tools are not sufficient to incentivise any renewables development, but combined they create a second market that trades in TGCs and which creates an additional revenue stream for the renewables firm and an additional cost to be incurred by the brown firm. If either the obligation quota or the buy-out price is set to zero by the government, than the brown firm will not participate in the TGC market and no transactions will take place. The electricity market will behave as normal.

The market for green certificates was found to have only two functional prices; the TGCs would trade at a price equal to the buy-out price or the certificates would trade at zero.

When the obligation quota is set at a quantity greater than the amount of certificates that will be produced in any one period, the market power belongs to the renewables producer. Prices will be as high as the green firm can demand from the brown firm. This could be a very significant cost to the brown firm give the imbalance of relative negotiating strengths. But with the brown firm has an option to pay a buy-out price instead of purchasing certificates, so the green firm perceives a TGC price ceiling beyond which the brown firm will chose the buy-out option. For any TGC production in excess of the obligation quota, no demand will exist and the price will be zero. The brown firm is a rational and profit maximizing entity, it will not purchase TGCs beyond the quantity the government demands it submit. So the TGC market price will be either equal to the government set buy-out price up to the quantity of the government set obligation, or TGC price will be zero for any quantity above the obligation.

It was determined that a sub-game perfect equilibrium does exist between the two firms, once the government has established and declared the obligation quota and the buy-out price. Once the two policy variables have been set, there is a unique price and quantity which both firms will trade their goods; TGCs and electricity.

However, the model showed no optimal equilibrium value existed that the government could select for the two variables. The government had one exogenous constraint placed on it by politicians. A political acceptable price increase of electricity for the new program could not be exceeded. There was shown to be a quasi-infinite number of combinations of the buy-out price and obligation quota that would suffice to increase green energy production but not exceed the political price constraint.

It was also found that as the buy-out price increased the expansion of green energy production was greater than the reduced production caused by the brown firm's additional costs of the TGCs. As a result, at lower obligation quotas, the market for electricity experienced an outward supply curve shift. This shift resulted in an equilibrium point with a greater quantity of electricity being supplied at a lower price than that of a power market with no ancillary green certificate trading.

However, after some critical level for the obligation quota, this situation reverses itself. The net change in electric power production is downward; this is the result of the brown firm's reduced production being greater than any increase in production by the green firm. The electricity market supply curve has shifted inward, with a new equilibrium being a higher price and lower quantity.

Finally, it was shown that the government could endogenously determine an optimal equilibrium using the two policy variables and the political price constraint. By designating any two of the three variables, the third could be determined. For example, if the political price constraint is explicitly stated and the quantity of renewables generation (obligation quota) is assigned, then the optimal value of the buy-out option is determined. After which the two power firms will adjust to their own optimal equilibriums.

For further research, and to develop a better understanding of how an actual TGC market and power market may interact, there are several modifications that could be examined within this model.

The first modification would be to expand the number players in the competitive-fringe. In this model there is only one, who by it nature was a sole producer of green certificates. Expanding the model to include numerous fringe players, all of them small and identical, would be a more accurate portrayal of the actual markets and may provide insights into the TGC market development.

The second modification would be to have differentiated costs structures for the multiple fringe players. The final modification would be to have an oligopoly of dominant firms, instead of a single dominant firm. All of these modifications have the possibility of providing deferent results from that were found in the current model.

**Policy Issues**

This dissertation has examined several aspects of Scotland's movement to increase deployment and use of renewable energy. Specifically, it was oriented to the issues of electricity production. The some of the essential mechanisms have been put in place to move forward and have significant amounts of power production come from renewables.

The Renewables Obligation (Scotland) has created an investment climate that large amounts of private capital are moving into a business sector that heretofore had been unable to demonstrate profits without direct government financial support. Private firms in the energy sector have been left to their own devises to seek efficiency and profits with any of the eligible renewable power technologies.

A potential problem has arisen as a result of this hand off policy. Commercial energy developers are using only technologies with the highest potential profits. So the vast majority of renewables projects being proposed to date are onshore wind farms. A very visible "rush for wind" is occurring in Scotland and the rest of the United Kingdom. Other profitable renewables projects are being developed, but in relatively inconsequential quantities.

Wind farms were on the cusp of being profitable before the ROS was enacted, but the additional revenues now earned by the sale of ROCs, has made them highly profitable. Other technologies, which are still not profitable, even at the current earnings levels, continue to need government funding and support for on going research and development.

Many of the technologies that are yet to be commercialized have the least environmental impact, as estimated by the implicit prices derived in the choice experiment in Chapter 4. Submersed marine technologies will have no landscape impact and may have no impact on fisheries, although it is too early in testing of these systems to have certainty of this last point.

Onshore wind farms were shown to have a substantial negative landscape effect and stated preferences were found to show a low WTP for this form of energy production, depending on the scale of the project.

While there is a large and consistently positive attitude expressed by the general population toward renewables, a question remains as to the accumulation effect of too many wind farms being constructed in Scotland. Wind farms development and deployment should progress at a good pace if wind farms are located and constructed in a manner that minimizes environmental impacts on local residents and does not disrupt commercial interests like tourism.

The government should consider having minimum productivity requirements for a wind farm to be permitted. There is the potential that well placed and highly efficient farms may not be deployed as a result of the accumulation effect in some regions, while lower quality farms which were permitted earlier are constructed.

It is clear that the ROS has been highly effective in motivating new deployment of renewable energy facilities. Possibly too well. Economic profit will motivate entry into the market by new firms or expansion of existing firms. The quantity of speculation with deployment new farms may indicate that the economics profits are too large and the social welfare cost to consumers is more than necessary for the policy objective.

There is a perverse incentive in the ROS as it now stands. Given the annual ratcheting up of the buyout price and the obligation quota, firms which are already in the market have an incentive to obstruct new firms from entering. The value of ROCs increases as the quantity of ROC falls short of the obligation quota.

Only landfill gas and wind farms power projects are being intensely deployed in Scotland. All other technologies are still too costly for deployment, even with the ROC premium. Commercial enterprises have not increased their research and development budgets for developing alternative technologies because these technologies are still too distant from being financially competitive. Banding of technologies, giving special ROC incentives or credits, may be necessary to stimulate firms to risk more on research. Use of feed-in-tariffs may be necessary for some of these less advanced technologies.

Rural communities are most likely to be affected by large renewables projects. Policies which assure that adequate benefits are derived for the environmental costs incurred should be put in place.

And finally, the level of electricity price increases anticipated from the deployment of green technologies does appear to be as important to most households as feared by some politicians and activist groups. However, those households on the margin of fuel poverty must be given special assistance as even a 5% increase is a hardship.

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# Appendix A

Dear (name of person)

The University Of Glasgow is conducting research on renewable energy development in Scotland. Your household has been selected to participate in a survey that seeks people's opinions on the impacts that may result from new renewable energy projects. This research is being funded by the Scottish Economic Policy Network with a goal of promoting academic research on issues that are of special interest to the Scottish Parliament. This is a chance for your opinion to be heard as this research will be published and made available to the public, conservation groups, government, industry, and anyone concerned for Scotland's future.

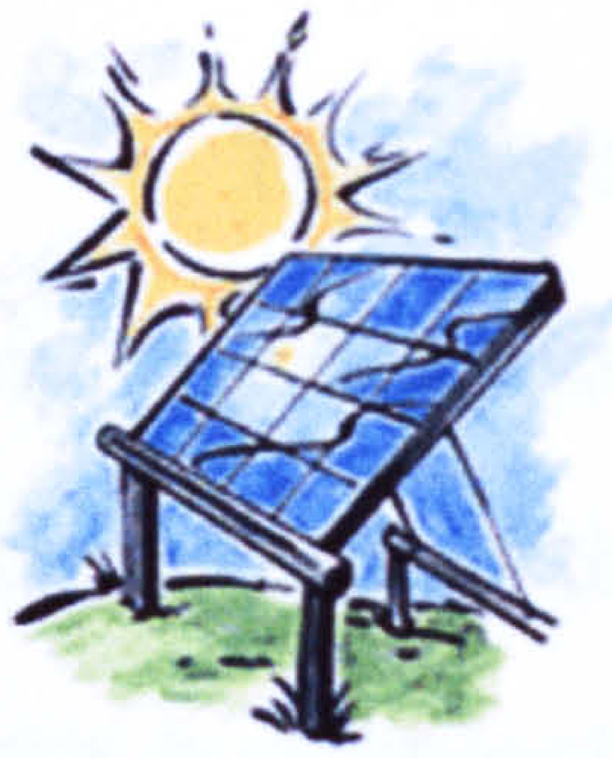
The Scottish Executive has committed itself to expanding the use of renewable energy resources, the primary reasons being environmental (concerns about climate change) and economic (creating new jobs and export opportunities). The type of renewable energy projects we are talking about are more than just wind farms (on-shore and off-shore), but also include hydroelectric schemes, power plants that burn wood, farm waste and household refuse, solar panels on houses, facilities that extract natural gas from land fills, and shoreline power plants that use wave or tidal energy.

Your household is one of 500 throughout Scotland, chose randomly from the electoral registrar. By completing and returning this survey you have the chance to voice your opinion about the future of renewable energy development in Scotland. *You may be assured of complete anonymity and confidentiality of all information given to us, none of which will be passed on to anyone else.*

As a sign of appreciation, 1 out of every 100 surveys that are returned will be randomly chosen to receive a £20 prize: replies must be received by 30 September 2003. If you have any questions about this survey please contact myself, or Ariel Bergmann (Ph.D. research student) at 0141 330 3385, email: scotlandresearch@yahoo.co.uk. Thank you for your help.

Yours sincerely,

Professor Nick Hanley




UNIVERSITY OF GLASGOW
DEPARTMENT OF ECONOMICS


# IMPACTS FROM RENEWABLE ENERGY DEVELOPMEMT IN SCOTLAND

## A SURVEY OF PEOPLE'S VIEWS

AUTUMN 2003


The Scottish Executive and the U.K. Government have committed themselves to an expansion of renewable energy development during the next decade. Examples of renewable energy are hydroelectric schemes, windmills (onshore and offshore), solar panels for heat or electricity, tidal and wave power, and burning household rubbish and forest or agricultural waste.

This commitment to increase the use of renewable energy sources is partly due to concerns over global warming (climate change). The U.K. has agreed to many European Community and International treaties that mean we have to reduce the amount of green house gases (climate change gases) produced by the use of fossil fuels (coal, oil and gas) for electric power generation. Investing in renewable energy also offers the prospect of future jobs in Scotland, as a major growth sector.

**This survey aims to find out what people would prefer to happen in Scotland from all the new renewable energy construction and development that will occur during the next 10 to 15 years.**

1 in every 100 surveys returned will be randomly selected to receive a £20 prize. If you would like to be included, please give us your name and address.

Name______________________

Address ______________________________

If you would like to receive a copy of our results once they are ready, please tick this box ☐

Please reply by 30 September 2003

This survey looks at five different kinds of <u>impacts</u> that renewable energy projects might have. These are:

* Landscape * Wildlife * Air Pollution
* Employment * Price of electricity

All the different kinds of renewable energy (wind farms, hydro power stations, etc.) have some or all of these kinds of impacts and it's these impacts that our survey focuses on.

WHAT ARE THESE IMPACTS?

<u>Landscape</u> - How large a project is can influence how much visual impact results, but the location of the project is also very important. For example, a wind farm could have 3 or 30 windmills and the wind farm could be located in an industrial estate or in a national park. Size and location also matter for new hydroelectric schemes.

<u>Wildlife</u> - The effect on wildlife from renewable energy development can range from harming wildlife a little to actually helping it a little, but in many cases there will be no effect. For example, hydroelectric dams can prevent salmon from swimming up rivers. Farmland that is used to grow energy crops allows for healthier wildlife. However, the government would not allow projects that had large negative effects on wildlife.

**Air Pollution** - Many types of renewable energy projects create no air pollution at all. Some projects do create a low level of air pollution, for example, burning household rubbish at a power station, but this is a very small amount compared to when electricity is being generated from burning coal or natural gas.

jobs

**Employment** - All renewable energy projects will create new long-term employment in local communities. Renewable energy projects require operational and maintenance workers that tend to be skilled or technically trained. These jobs pay above average wages. People will also be employed during construction, but these are not long-term jobs in the local community.

£

**The price of electricity**- A large expansion of renewable energy in Scotland may cause an increase in electricity prices. An average household currently pays about £270 a year for electricity (which is about £68 a quarter). However, this would probably go up if Scotland goes ahead with using more and more renewable energy rather than traditional energy from oil, gas, and coal.

In the next part of this questionnaire, we are going to ask you to choose between two possible renewable energy projects that maybe built in Scotland. Each plan is described in terms of its impacts; that is, in terms of what it would mean for landscape, wildlife, air pollution, jobs and electricity prices. Here is an example:

option example

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE<br>visual impact caused by location and/or size | HIGH | NONE | No increase in renewable energy |
|  | WILDLIFE<br>health of habitat | SLIGHT HARM | SLIGHT HARM | Alternative climate change programs used |
|  | AIR POLLUTION | NONE | NONE | |
|  jobs | EMPLOYMENT<br>new jobs in local community | 8-12 JOBS | 1-3 JOBS | North Sea gas fired power stations instead |
| £ | PRICE OF ELECTRICITY<br>additional rates per year | £16<br>per year | £7<br>per year | |
| | YOUR CHOICE:<br>(please tick one only) | A<br>☐ | B<br>☐ | I would not want either A or B<br>☐ |

You will see that each plan has different combinations of impacts. In this example you can see that Plan A has high visual impact, 8-12 new jobs created and an increase in electricity bills of £16 per year, while Plan B has no visual impact, 1-3 new jobs created, and an increase of £7 per year for electricity. But the impacts on air pollution and wildlife are the same in both Plan A and Plan B.

"Neither" means that we do not go ahead with renewable energy at all - we just keep on using fossil fuels like North Sea gas. However choosing this option would mean missing out on all of the benefits of renewable energy. Also, the government would have to pursue other means of reducing the use of fossil fuels, for example, increased petrol taxes and forcing businesses to invest in energy efficiency measures, costs that may be passed on to consumers.

In each of the options that follow, we just ask you which plan you would prefer to go ahead. There are no wrong or right answers; we are simply interested in your opinion. So, please go through each of the 4 options, and for each one tick either "Plan A", "Plan B" or "Neither". Make sure you only tick one box for each option!

option 1

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE<br>visual impact caused by location and/or size | HIGH | NONE | *No increase in renewable energy<br>*Alternative climate change programs used<br><br>*North Sea gas fired power stations instead |
|  | Wildlife<br>health of habitat | NONE | SLIGHT HARM | |
|  | Air Pollution | NONE | NONE | |
|  jobs | Employment<br>new jobs in local community | 1-3 JOBS | 1-3 JOBS | |
| £ | Price of electricity<br>additional rates per year | £7 | £29 | |
| | YOUR CHOICE:<br>(please tick one only) | A<br>☐ | B<br>☐ | I would not want either A or B<br>☐ |

option 2

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE<br>visual impact caused by location and/or size | NONE | MODERATE | *No increase in renewable energy<br>*Alternative climate change programs used<br><br>*North Sea gas fired power stations instead |
|  | Wildlife<br>health of habitat | SLIGHT IMPROVEMENT | SLIGHT IMPROVEMENT | |
|  | Air Pollution | SLIGHT INCREASE | NONE | |
|  jobs | Employment<br>new jobs in local community | 1-3 JOBS | 8-12 JOBS | |
| £ | Price of electricity<br>additional rates per year | £7 | £0 | |
| | YOUR CHOICE:<br>(please tick one only) | A<br>☐ | B<br>☐ | I would not want either A or B<br>☐ |

## option 3

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | **LANDSCAPE** visual impact caused by location and/or size | NONE | NONE | *No increase in renewable energy<br>*Alternative climate change programs used<br><br>*North Sea gas fired power stations instead |
| | **Wildlife** health of habitat | SLIGHT IMPROVEMENT | SLIGHT HARM | |
| | **Air Pollution** | NONE | SLIGHT INCREASE | |
| jobs | **Employment** new jobs in local community | 8-12 JOBS | 20-25 JOBS | |
| £ | **Price of electricity** additional rates per year | £45 | £0 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

## option 4

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | **LANDSCAPE** visual impact caused by location and/or size | HIGH | MODERATE | *No increase in renewable energy<br>*Alternative climate change programs used<br><br>*North Sea gas fired power stations instead |
| | **Wildlife** health of habitat | SLIGHT HARM | NONE | |
| | **Air Pollution** | NONE | SLIGHT INCREASE | |
| jobs | **Employment** new jobs in local community | 8-12 JOBS | 8-12 JOBS | |
| £ | **Price of electricity** additional rates per year | £16 | £29 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

**Overall which of these is impacts is most important to you?** (Please tick only one)

Landscape _____ Wildlife _____ Air Pollution _____

Employment _____ Price of electricity _____

16.9.3.10e

Finally, we would like to ask you some questions about yourself. This will help in understanding your choices and help us to make sure that our survey is representative of the Scottish people. Remember that all information you give will be kept confidential and anonymous.

About yourself:

Do you live in: a city ____ a small town ____ a village/the country ____

Do you have any children? Yes No

Do you work in the energy sector? Yes No

Roughly how much was your last electric bill? __________

Are you a member of a conservation group? Yes No

What is you gross (i.e., before tax) household income?

| | | | |
|---|---|---|---|
| < £10,000 | ___ | £46,000-£50,999 | ___ |
| £10,000-£15,999 | ___ | £51,000-£55,999 | ___ |
| £16,000-£20,999 | ___ | £56,000-£60,999 | ___ |
| £21,000-£25,999 | ___ | £61,000-£65,999 | ___ |
| £26,000-£30,999 | ___ | £66,000-£70,999 | ___ |
| £31,000-£35,999 | ___ | £71,000-£75,999 | ___ |
| £36,000-£40,999 | ___ | £76,000-£79,999 | ___ |
| £41,000-£45,999 | ___ | £80,000+ | ___ |

How old are you?
younger than 25 ___ 25-40 ___ 41-54 ___ 55-65___ older than 65 ___

Which of the following best describes your level of education?
school only ____ college ____ university ____

**We would be interested to have any additional comments you may have on this issue of renewable energy development in Scotland**

Thanks for your time – now please post your reply back to us using the envelope provided.

# Appendix B

option 1

| | Plan A | Plan B | Neither |
|---|---|---|---|
| LANDSCAPE<br>visual impact caused by location and/or size | HIGH | NONE | *No increase in renewable energy<br>*Alternative climate change programs used<br>*North Sea gas fired power stations instead |
| Wildlife<br>health of habitat | NONE | SLIGHT HARM | |
| Air Pollution | NONE | NONE | |
| jobs Employment<br>new jobs in local community | 1-3 JOBS | 1-3 JOBS | |
| £ Price of electricity<br>additional rates per year | £7 | £29 | |
| YOUR CHOICE:<br>(please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 2

| | Plan A | Plan B | Neither |
|---|---|---|---|
| LANDSCAPE<br>visual impact caused by location and/or size | NONE | MODERATE | *No increase in renewable energy<br>*Alternative climate change programs used<br>*North Sea gas fired power stations instead |
| Wildlife<br>health of habitat | SLIGHT IMPROVEMENT | SLIGHT IMPROVEMENT | |
| Air Pollution | SLIGHT INCREASE | NONE | |
| jobs Employment<br>new jobs in local community | 1-3 JOBS | 8-12 JOBS | |
| £ Price of electricity<br>additional rates per year | £7 | £0 | |
| YOUR CHOICE:<br>(please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 3

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE visual impact caused by location and/or size | NONE | NONE | *No increase in renewable energy *Alternative climate change programs used |
| | Wildlife health of habitat | SLIGHT IMPROVEMENT | SLIGHT HARM | |
| | Air Pollution | NONE | SLIGHT INCREASE | |
| jobs | Employment new jobs in local community | 8-12 JOBS | 20-25 JOBS | *North Sea gas fired power stations instead |
| £ | Price of electricity additional rates per year | £45 | £0 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 4

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE visual impact caused by location and/or size | HIGH | MODERATE | *No increase in renewable energy *Alternative climate change programs used |
| | Wildlife health of habitat | SLIGHT HARM | NONE | |
| | Air Pollution | NONE | SLIGHT INCREASE | |
| jobs | Employment new jobs in local community | 8-12 JOBS | 8-12 JOBS | *North Sea gas fired power stations instead |
| £ | Price of electricity additional rates per year | £16 | £29 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

**Overall which of these is impacts is most important to you?** (Please tick only one)

Landscape _____ Wildlife _____ Air Pollution _____

Employment _____ Price of electricity _____

16.9.3.10e

option 1

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE<br>visual impact caused by location and/or size | NONE | NONE | *No increase in renewable energy<br>*Alternative climate change programs used<br>*North Sea gas fired power stations instead |
| | Wildlife<br>health of habitat | NONE | NONE | |
| | Air Pollution | SLIGHT INCREASE | NONE | |
| jobs | Employment<br>new jobs in local community | 20-25 JOBS | 1-3 JOBS | |
| £ | Price of electricity<br>additional rates per year | £16 | £0 | |
| | YOUR CHOICE:<br>(please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 2

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE<br>visual impact caused by location and/or size | NONE | LOW | *No increase in renewable energy<br>*Alternative climate change programs used<br>*North Sea gas fired power stations instead |
| | Wildlife<br>health of habitat | NONE | SLIGHT IMPROVEMENT | |
| | Air Pollution | NONE | NONE | |
| jobs | Employment<br>new jobs in local community | 8-12 JOBS | 20-25 JOBS | |
| £ | Price of electricity<br>additional rates per year | £16 | £45 | |
| | YOUR CHOICE:<br>(please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 3

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE visual impact caused by location and/or size | LOW | LOW | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
|  | Wildlife health of habitat | SLIGHT IMPROVEMENT | NONE | |
|  | Air Pollution | SLIGHT INCREASE | NONE | |
|  jobs | Employment new jobs in local community | 1-3 JOBS | 1-3 JOBS | |
| £ | Price of electricity additional rates per year | £16 | £0 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 4

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE visual impact caused by location and/or size | LOW | NONE | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
|  | Wildlife health of habitat | SLIGHT HARM | SLIGHT IMPROVEMENT | |
|  | Air Pollution | NONE | SLIGHT INCREASE | |
|  jobs | Employment new jobs in local community | 8-12 JOBS | 8-12 JOBS | |
| £ | Price of electricity additional rates per year | £7 | £7 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

**Overall which of these is impacts is most important to you?** (Please tick only one)

Landscape _____ Wildlife _____ Air Pollution _____

Employment _____ Price of electricity _____

1.21.19.14e

option 1

<table>
<tr><th></th><th></th><th>Plan A</th><th>Plan B</th><th>Neither</th></tr>
<tr><td></td><td>LANDSCAPE<br>visual impact caused by location and/or size</td><td>MODERATE</td><td>LOW</td><td rowspan="5">*No increase in renewable energy<br>*Alternative climate change programs used<br>*North Sea gas fired power stations instead</td></tr>
<tr><td></td><td>Wildlife<br>health of habitat</td><td>NONE</td><td>NONE</td></tr>
<tr><td></td><td>Air Pollution</td><td>NONE</td><td>SLIGHT INCREASE</td></tr>
<tr><td>jobs</td><td>Employment<br>new jobs in local community</td><td>20-25 JOBS</td><td>8-12 JOBS</td></tr>
<tr><td>£</td><td>Price of electricity<br>additional rates per year</td><td>£7</td><td>£29</td></tr>
<tr><td></td><td>YOUR CHOICE:<br>(please tick one only)</td><td>A<br>☐</td><td>B<br>☐</td><td>I would not want either A or B<br>☐</td></tr>
</table>

option 2

<table>
<tr><th></th><th></th><th>Plan A</th><th>Plan B</th><th>Neither</th></tr>
<tr><td></td><td>LANDSCAPE<br>visual impact caused by location and/or size</td><td>HIGH</td><td>MODERATE</td><td rowspan="5">*No increase in renewable energy<br>*Alternative climate change programs used<br>*North Sea gas fired power stations instead</td></tr>
<tr><td></td><td>Wildlife<br>health of habitat</td><td>NONE</td><td>SLIGHT IMPROVEMENT</td></tr>
<tr><td></td><td>Air Pollution</td><td>SLIGHT INCREASE</td><td>NONE</td></tr>
<tr><td>jobs</td><td>Employment<br>new jobs in local community</td><td>1-3 JOBS</td><td>1-3 JOBS</td></tr>
<tr><td>£</td><td>Price of electricity<br>additional rates per year</td><td>£45</td><td>£16</td></tr>
<tr><td></td><td>YOUR CHOICE:<br>(please tick one only)</td><td>A<br>☐</td><td>B<br>☐</td><td>I would not want either A or B<br>☐</td></tr>
</table>

20.6.7.23

## option 3

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE visual impact caused by location and/or size | NONE | MODERATE | *No increase in renewable energy *Alternative climate change programs used |
| | Wildlife health of habitat | NONE | SLIGHT HARM | |
| | Air Pollution | NONE | SLIGHT INCREASE | |
| jobs | Employment new jobs in local community | 8- 12 JOBS | 1-3 JOBS | *North Sea gas fired power stations instead |
| £ | Price of electricity additional rates per year | £45 | £45 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

## option 4

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE visual impact caused by location and/or size | HIGH | NONE | *No increase in renewable energy *Alternative climate change programs used |
| | Wildlife health of habitat | SLIGHT IMPROVEMENT | SLIGHT IMPROVEMENT | |
| | Air Pollution | SLIGHT INCREASE | NONE | |
| jobs | Employment new jobs in local community | 8-12 JOBS | 1-3 JOBS | *North Sea gas fired power stations instead |
| £ | Price of electricity additional rates per year | £0 | £29 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

**Overall which of these is impacts is most important to you?** (Please tick only one)

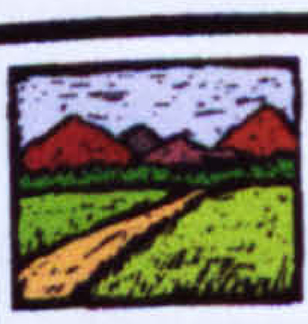
Landscape _____ Wildlife _____ Air Pollution _____

Employment _____ Price of electricity _____

option 1

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE visual impact caused by location and/or size | NONE | HIGH | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
|  | Wildlife health of habitat | SLIGHT HARM | NONE | |
|  | Air Pollution | NONE | NONE | |
|  jobs | Employment new jobs in local community | 1-3 JOBS | 1-3 JOBS | |
| £ | Price of electricity additional rates per year | £29 | £7 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 2

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE visual impact caused by location and/or size | MODERATE | NONE | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
|  | Wildlife health of habitat | SLIGHT IMPROVEMENT | SLIGHT IMPROVEMENT | |
|  | Air Pollution | NONE | SLIGHT INCREASE | |
|  jobs | Employment new jobs in local community | 8-12 JOBS | 1-3 JOBS | |
| £ | Price of electricity additional rates per year | £0 | £7 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

5.11.18.4r

option 3

| | Plan A | Plan B | Neither |
|---|---|---|---|
| **LANDSCAPE** visual impact caused by location and/or size | NONE | NONE | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
| **Wildlife** health of habitat | SLIGHT HARM | SLIGHT IMPROVEMENT | |
| **Air Pollution** | SLIGHT INCREASE | NONE | |
| **Employment** new jobs in local community (jobs) | 20-25 JOBS | 8-12 JOBS | |
| **£ Price of electricity** additional rates per year | £0 | £45 | |
| YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 4

| | Plan A | Plan B | Neither |
|---|---|---|---|
| **LANDSCAPE** visual impact caused by location and/or size | MODERATE | HIGH | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
| **Wildlife** health of habitat | NONE | SLIGHT HARM | |
| **Air Pollution** | SLIGHT INCREASE | NONE | |
| **Employment** new jobs in local community (jobs) | 8-12 JOBS | 8-12 JOBS | |
| **£ Price of electricity** additional rates per year | £29 | £16 | |
| YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

**Overall which of these is impacts is most important to you?** (Please tick only one)

Landscape _____ Wildlife _____ Air Pollution _____

Employment _____ Price of electricity _____

option 1

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE<br>visual impact caused by location and/or size | NONE | NONE | *No increase in renewable energy<br>*Alternative climate change programs used<br>*North Sea gas fired power stations instead |
| | Wildlife<br>health of habitat | NONE | NONE | |
| | Air Pollution | NONE | SLIGHT INCREASE | |
| jobs | Employment<br>new jobs in local community | 1-3 JOBS | 20-25 JOBS | |
| £ | Price of electricity<br>additional rates per year | £0 | £16 | |
| | YOUR CHOICE:<br>(please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 2

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE<br>visual impact caused by location and/or size | LOW | NONE | *No increase in renewable energy<br>*Alternative climate change programs used<br>*North Sea gas fired power stations instead |
| | Wildlife<br>health of habitat | SLIGHT IMPROVEMENT | NONE | |
| | Air Pollution | NONE | NONE | |
| jobs | Employment<br>new jobs in local community | 20-25 JOBS | 8-12 JOBS | |
| £ | Price of electricity<br>additional rates per year | £45 | £16 | |
| | YOUR CHOICE:<br>(please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

8.25.15.2r

option 3

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE visual impact caused by location and/or size | MODERATE | NONE | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
| | Wildlife health of habitat | SLIGHT HARM | NONE | |
| | Air Pollution | SLIGHT INCREASE | NONE | |
| jobs | Employment new jobs in local community | 1-3 JOBS | 8- 12 JOBS | |
| £ | Price of electricity additional rates per year | £45 | £45 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 4

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE visual impact caused by location and/or size | NONE | HIGH | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
| | Wildlife health of habitat | SLIGHT IMPROVEMENT | SLIGHT IMPROVEMENT | |
| | Air Pollution | NONE | SLIGHT INCREASE | |
| jobs | Employment new jobs in local community | 1-3 JOBS | 8-12 JOBS | |
| £ | Price of electricity additional rates per year | £29 | £0 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

**Overall which of these is impacts is most important to you?** (Please tick only one)

Landscape _____ Wildlife _____ Air Pollution _____

Employment _____ Price of electricity _____

22.12.10.24r

option 1

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE visual impact caused by location and/or size | LOW | MODERATE | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
|  | Wildlife health of habitat | NONE | NONE | |
|  | Air Pollution | SLIGHT INCREASE | NONE | |
|  jobs | Employment new jobs in local community | 8-12 JOBS | 20-25 JOBS | |
| £ | Price of electricity additional rates per year | £29 | £7 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 2

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
|  | LANDSCAPE visual impact caused by location and/or size | MODERATE | HIGH | *No increase in renewable energy *Alternative climate change programs used *North Sea gas fired power stations instead |
|  | Wildlife health of habitat | SLIGHT IMPROVEMENT | NONE | |
|  | Air Pollution | NONE | SLIGHT INCREASE | |
|  jobs | Employment new jobs in local community | 1-3 JOBS | 1-3 JOBS | |
| £ | Price of electricity additional rates per year | £16 | £45 | |
| | YOUR CHOICE: (please tick one only) | A ☐ | B ☐ | I would not want either A or B ☐ |

option 3

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE<br>visual impact caused by location and/or size | LOW | LOW | *No increase in renewable energy<br>*Alternative climate change programs used |
| | Wildlife<br>health of habitat | NONE | SLIGHT IMPROVEMENT | |
| | Air Pollution | NONE | SLIGHT INCREASE | |
| jobs | Employment<br>new jobs in local community | 1-3 JOBS | 1-3 JOBS | *North Sea gas fired power stations instead |
| £ | Price of electricity<br>additional rates per year | £0 | £16 | |
| | YOUR CHOICE:<br>(please tick one only) | A<br>☐ | B<br>☐ | I would not want either A or B<br>☐ |

option 4

| | | Plan A | Plan B | Neither |
|---|---|---|---|---|
| | LANDSCAPE<br>visual impact caused by location and/or size | NONE | LOW | *No increase in renewable energy<br>*Alternative climate change programs used |
| | Wildlife<br>health of habitat | SLIGHT IMPROVEMENT | SLIGHT HARM | |
| | Air Pollution | SLIGHT INCREASE | NONE | |
| jobs | Employment<br>new jobs in local community | 8-12 JOBS | 8-12 JOBS | *North Sea gas fired power stations instead |
| £ | Price of electricity<br>additional rates per year | £7 | £7 | |
| | YOUR CHOICE:<br>(please tick one only) | A<br>☐ | B<br>☐ | I would not want either A or B<br>☐ |

**Overall which of these is impacts is most important to you?** (Please tick only one)

Landscape _____ Wildlife _____ Air Pollution _____

Employment _____ Price of electricity _____

# Appendix C

Back of Post Card

Dear (name of person)

Last week a questionnaire seeking your opinion about renewable energy development was mailed to you. Your household was one of only 500 chosen to participate in this survey. If you have already completed and returned it to us please accept our sincere thanks. If not, please do so today. Because it has been sent to such a small sample of Scottish households, your response is important to assure that the study reflects all the views within Scotland. Please contact Ariel Bergmann at 0141.330.3385 or email: scotlandresearch@yahoo.com.uk if you have any questions.

Sincerely Professor Nick Hanley

Front of Post Card

Renewable Energy Impact Study
University of Glasgow
Economics Department
Adam Smith Building
Glasgow G12 8RT

XXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXX

UNIVERSITY
*of*
GLASGOW

# Appendix D

# Report for University of Glasgow
# Renewable Energy
# Synopsis of Focus Group Responses

*Author: Maggie Dewar*
*Focus Ecosse*
*3 Caithness Row*
*New Lanark*
*ML11 9DG*

### 1.1. Background Information

This report, commissioned by the University of Glasgow, contains preliminary research to determine what 'characteristics' of 'green' or renewable energy production were regarded as 'good' or 'bad' by a cross-section of the Scottish public. The findings reported below, will be the first step in gathering information for the University and ultimately other decision-makers (for renewable energy) within Scotland. The preliminary report contains the opinions of focus groups, recruited from the general public.

### 1.2. Composition of Focus Groups

Two focus groups were recruited: one rural (New Lanark), one urban (Glasgow). Each group contained a balance of genders and ages and drew from a pool of B,C and D categories.

The New Lanark focus group contained residents from the village of New Lanark itself and other rural areas (Carluke, Biggar, Crossford). New Lanark is a restored mill village in South Lanarkshire and was an interesting place to study because there was an existing hydro-electric station which had been existence for more than 200 years. Because this could have sensitised the participants, members were also recruited from outside New Lanark. Having local knowledge of a particular type of renewable energy could have worked both ways – that is residents may have been more aware of disadvantages or advantages of hydro technology.

The urban focus group was drawn from a pool of staff (secretaries and porters) working for the University of Glasgow and some past students. This group contained 12 participants compared to New Lanark (8 participants).

### 1.3. Structure of Sessions

Given the nature of the subject and the possible diversity of the two groups, it was decided that it was important to establish the levels of pre-existing knowledge regarding renewable energy, and uncover any biases. To ensure uniformity and avoid biasing the discussions, a script was prepared and read (Appendix I).

Once read, the group were asked a series of questions:

- Name the renewable energy technologies you are familiar with.
- What characteristics of these technologies are (in your own opinion) good or bad
- Which technology would you favour most?
- Would you favour another technology if the energy installation's were on your own doorstep?

The group answers were written down on a flipchart (see results section). Transcriptions of the sessions can be found in Appendix II.

Following this 'brain-storming' session, the presenter from the University of Glasgow, briefly described the following technologies:

- Solar power
- Hydro power
- Tidal power
- Wood burning
- Landfill gas
- Wind

The presentation was designed to clear up questions raised during the discussion period and fill any knowledge gaps regarding types of renewable technology.

Upon completion of this presentation, the groups were sub-divided into groups of four and asked to complete an evaluation exercise. This consisted of asking each group to allocate a percentage to where they would like their money to be spent if they were allowed to nominate their favoured renewable energy technology.

Finally, each individual was asked to complete a questionnaire (Appendix III) to draw out their own personal opinions and any past and present perceptions regarding renewable energy technologies. Most importantly, it was intended to identify what characteristics of renewable energy they found most attractive.

## 2. Results

### 2.1. Results of Group 'Brain-storming'

Summary of Renewable Energy Sources identified by

**New Lanark**

- Water/Hydro
- Wind
- Solar
- Geothermal
- Tidal
- Wood
- Nuts/burning waste
- Dung/organic waste

**Glasgow**

- Wind
- Tidal/Wave
- Solar
- Hydro
- Domestic/Municipal waste
- Animal waste/dung
- Fermentation

As there was a great deal of similarity, where identical technologies were named by each group (hydro, solar, wind, tidal, organic waste) these shall be reported together

The New Lanark group seemed aware of geothermal energy and wood burning (which were not mentioned by the Glasgow group). However, the Glasgow group seemed aware of generation from fermentation processes (sugar cane). This was not discussed by New Lanark.

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## 2.2. Comparison of Renewable Energy Technologies discussed by both focus groups

### 2.2.1. Hydro Power Characteristics

**New Lanark**

| GOOD CHARACTERISTICS | BAD CHARACTERISTICS |
|---|---|
| Plentiful | Dams (unnatural, damage the environment) |
| Renewable | Large areas may be flooded |
| Clean | Reliant on climate |
| Cheap | Disturbs water tables |
| Used on different scales - flexible | Noisy |
| | Visible |

**Glasgow**

| GOOD CHARACTERISTICS | BAD CHARACTERISTICS |
|---|---|
| Easy to store | Ugly – big buildings |
| Some of the dams are quiet a tourist attraction (e.g. Pitlochry) | Dangerous (deaths at Barrhead Dam). Should be made out of bounds |
| Dependable | Dams destroy existing landscape/wildlife |
| Dams – low maintenance | Depends on weather – affected by drought |
| Cheap | Initially they change the environment for miles around |
| Reliable | |
| Fishing – encourages leisure & sports | |

Not surprisingly, there were similarities between both groups when they discussed bad characteristics. For instance, both felt that hydro power generation would cause problems because it could destroy the environment – e.g. when creating dams and flooding valleys. The groups also felt that hydro was rather dependent on climate (although NL felt water was plentiful at present). The New Lanark group expressed the opinion that hydro technology could also be noisy (possibly because certain members of the group had personal experience of this). The Glasgow group felt that hydro could be dangerous and could be unattractive (e.g. with big buildings).

There were interesting differences between groups as to what constituted 'good' characteristics. The New Lanark group felt it was clean, plentiful, cheap and flexible whereas the Glasgow group focused more on the fact it was easy to store, low maintenance, and encouraged fishing and tourism. It was strange that given New Lanark's position and the fact that the Falls of Clyde attract a large number of visitors per annum, that the New Lanark group did not list this as a positive attribute.

### 2.2.2. Wind Power

**New Lanark**

| GOOD CHARACTERISTIC | BAD CHARACTERISTIC |
|---|---|
| Aesthetically pleasing | Ugly |
| Clean | Noisy |
| Reliable | Expensive infrastructure |
| Plentiful | |
| Flexible size | |

**Glasgow**

| GOOD CHARACTERISTIC | BAD CHARACTERISTIC |
|---|---|
| Environmentally friendly | Noisy (depending on the size of the generator. Okay if they are out in the sea or the middle of nowhere.. say on hills) |
| Noise free | They vibrate |
| Low maintenance | Bad for birds and wildlife |
| Looks nice in pictures | Ugly – blot on the landscape |

Both groups agreed that wind farms could be ugly and noisy. New Lanark also felt that the infra-structure of building and maintaining windmills could be expensive. Glasgow noted that windmills interfered with wildlife. Strangely enough, members within each focus syndicate also felt windmills were aesthetically pleasing! The Glasgow group disagreed within itself and stated that windmills were noise free.

Generally, it was felt that wind power was clean, reliable and plentiful. New Lanark were also keen on the fact that the technology was flexible and could be adapted by individual householders as well as on a larger scale.

### 2.2.3. Solar Energy

**New Lanark**

| GOOD CHARACTERISTIC | BAD CHARACTERISTIC |
|---|---|
| Clean | Expensive for households to install and maintain |
| Flexible | Need a big area |
| Easily installed | What happens in winter? |
| Good for households | Intermittent |
| Personalised | Need building regs / impact on the value of your property |
| Cheap | Don't know who owns it |

**Glasgow**

| GOOD CHARACTERISTIC | BAD CHARACTERISTIC |
|---|---|
| Cheap to run | Difficult to rely on if it depends on the sun. |
| Natural | If it's reliant on just daylight hours you're going to produce less electricity in the winter when you need more. |
| Panels so each house can generate it's own electricity | Ugly – but you can hide it on roofs |
| Adaptable – it's portable and can be hidden anywhere | High maintenance – do they burn out? |
| Can store small amounts | Easily vandalised |

Solar energy possibly prompted most discussion within each session. The New Lanark group felt it would be expensive and to install and maintain (on houses). It would also give rise to questions about building regulations, the impact on the value of property and indeed the question of who actually owns the panels. In contrast the Glasgow group did not express any such concerns but they did think the panels looked unattractive (but could be hidden), and could be easily vandalised. Both groups believed that there would be some issues regarding the lack of sun/daylight in Scotland. There were questions regarding the mechanics of the technology. These were answered later in the session.

Of the positive characteristics there was general agreement that it was a good technology because it could be used by individual householders and was therefore flexible and cheap. The New Lanark group liked the fact that it may be cheap, easily installed and clean. The Glasgow group also liked the fact that it was be natural and could be stored.

### 2.2.4. Tidal

**New Lanark**

| GOOD CHARACTERISTIC | BAD CHARACTERISTIC |
|---|---|
| Cheap | Distribution may be a problem |
| Sustainable | May have an environmental impact |
| Good for islands | Effects wildlife |
| Clean | Affects shipping |
| Not visible | |

**Glasgow**

| GOOD CHARACTERISTIC | BAD CHARACTERISTIC |
|---|---|
| Endless supply of waves | Location – accessibility difficult<br>Affects sea life and birds |
| Cheap | Unemployment – there wouldn't be the same amount of people employed to produce and maintain or anything like that |
| Natural | It takes up the seaside and the beach (not that Scottish beaches are very good – their too cold!) |
| Environmentally friendly | Depending on size and nearby beauty spots it could be unsightly as well, like a big pontoon floating across a beauty spot |
| | Maintenance – it could be dangerous because it's out to sea. Very, very hard to maintain. The very fact they're not in general use to a big scale probably points to that. |

Generally both groups were in agreement that tidal power was good because it was cheap, clean, sustainable and environmentally friendly.

There was an interesting point of difference in that New Lanark felt that the technology was not visible whereas the Glasgow group felt that potentially it could ruin existing beauty spots.

Both sessions agreed that tidal technology could have a detrimental affect on the environment and wildlife (also shipping for NL). Locality was a concern to both groups as it could create distribution and maintenance problems.

Interestingly, the Glasgow group expressed concern that this technology would create unemployment.

### 2.2.5. Waste / Dung

**New Lanark**

| GOOD CHARACTERISTICS | BAD CHARACTERISTICS |
|---|---|
| Gets rid of 'bad' gas | Burning causes pollution |
| Gas Flaring – better than putting waste into rivers | Needs collecting |
| Plentiful | Smelly |
| Reduces landfill | May produce harmful by-products |
| May encourage responsibility for recycling | Requires public to be educated |
| Reduces collections | |
| Could produce a good by-product | |

**Glasgow**

| GOOD CHARACTERISTICS | BAD CHARACTERISTICS |
|---|---|
| Reduces the amount of landfills | Take up a lot of space |
| Makes use of waste | Smells |
| Encourages responsibility and changes attitudes to the environment | Pollutes – burning |
| Creates employment | Bad for ozone layer |
| Cheap | Needs separated – needs lots of types of bin |
| Plentiful supply | Smelly |
| | Expensive to run |

Both forums expressed fears over pollution problems, smells, harmful by-products resulting from waste or dung being burned. New Lanark felt that there would be a problem regarding education of the public and Glasgow felt it would take up a lot of space, would need a separation system and would consequently be expensive to run.

On the positive side it was felt that it was a good thing to get rid of methane gas and reduce the number of landfills. Also positive was the fact that the source was plentiful and would encourage individual responsibility for re-cycling. New Lanark felt that it would have a positive effect on the health of rivers, as waste would no longer be pumped into them (from sewage works). The Glasgow group again raised the issue of employment – this time in job creation.

### 2.3. Other Technologies Identified by focus groups

#### 2.3.1. Geothermal Power

**New Lanark**

| GOOD CHARACTERISTICS | BAD CHARACTERISTICS |
|---|---|
| Uses heat from the ground | Relatively unknown |
| Good to combine with other systems | Costly |
| Good for small communities | Large amounts of land needed |
| Source is free | Negative effect on the earth |
| Not visible | Difficult to install |

It was interesting that half the New Lanark group had heard of this technology and even mentioned a scheme in Glasgow but the Glasgow group did not mention it.

**2.3.2. Wood burning**
**New Lanark**

| GOOD CHARACTERISTICS | BAD CHARACTERISTICS |
|---|---|
| Recycles waste | Burning causes pollution |
| Cleans up air | Trees new time to grow |
| Helps farmers diversify | Requires large areas of land |
| Trees | Changes the ecosystem |
| Look good | Takes nutrients from the earth/ affects the water table |
| | Education required |
| | May increase the cost of food and detrimentally affect the quality of food (if imports increase) |

**2.3.2. Fermentation**
**Glasgow**

| GOOD | BAD |
|---|---|
| Creates employment | Smells |
| Uses waste products | Needs a lot of space |
| | Open to abuse |
| | Expensive |

**2.2.1. Results of Sub-Group Valuation Exercise**

| Group 1 New Lanark | Percentage | Characteristic |
|---|---|---|
| Run of river | 20 | Water abundant in Scotland, Lots of room for several power stations, more aesthetic than other systems |
| Reservoirs | 20 | As above |
| Wave | 10 | As above |
| Wind | 20 | Lots of hills and valleys that will provide good areas for wind farms |
| Biomass | 10 | Prevents methane hitting the atmosphere and reduces global warming |
| Wood | 10 | Gives employment |

| Group 2 New Lanark | Percentage | Characteristic |
|---|---|---|
| Hydro (run of river) | 21 | Abundant |
| Tidal | 20 | Saves pollution, by-product useful, provides employment, reduces waste |
| Biomass | 39 | Plentiful & clean |
| On shore wind power | 19 | |
| Solar panels | 1 | |

| Group 3 Glasgow | Percentage | Characteristic |
|---|---|---|
| Solar power | 40 | Can be stored, environmentally friendly, can be hidden |
| Hydro-electric | 40 | Plenty of rain, scenic, low maintenance, fish farms |
| Tidal | 20 | Natural, unlimited supply, cheap |

| Group 4 Glasgow | Percentage | Characteristic |
|---|---|---|
| Solar | 75 | Cheap, natural, hidden, no effect on the environment, cost effective |
| Hydro | 12.5 | Highly efficient, low maintenance, low impact on the environment |
| Recycling | 12.5 | Uses natural produce, more access (involvement) for people |

| Group 5 Glasgow | Percentage | Characteristic |
|---|---|---|
| Biomass | 50 | Re-cyclable, neutral effect on the environment |
| Hydro-electric | 40 | Uses what is available, environment recovers from construction |
| Photo- voltaic | 10 | Makes us aware |

### 2.2.2. Overall Summary of Valuation Exercise

| Technology | NL 1 | NL 2 | G 1 | G2 | G3 |
|---|---|---|---|---|---|
| Hydro | 40 | 21 | 40 | 12.5 | 40 |
| Solar | | 1 | 40 | 75 | 10 |
| Biomass | 10 | 39 | | | 50 |
| Recycling | | | | 12.5 | |
| Tidal | 20 | 20 | 20 | | |
| Wind | 20 | 19 | | | |
| Wood | 10 | | | | |

The table above summarises the results of the rating exercise. Groups of four were asked to allocate percentages to the renewable energy sources they felt would be most suitable for Scotland. Hydro electricity was chosen by all five groups, followed by, solar, biomass and tidal energy. It was interesting that the New Lanark groups both selected wind power whereas the Glasgow groups did not select this as an option. The Glasgow group also never selected wood burning as a desirable renewable energy technology.

The characteristics that seemed to appeal most to the focus group members were abundance, beneficial or neutral effect on the environment, naturalness, efficiency and low maintenance. The summary of the individual responses summarises this more accurately (see below).

### 2.3. Individual Responses

**2.3.1. Question 'Before this evening, what sources of renewable energy did you know about (please list)?:'**

| Energy Technology | Lanark Focus Group | Glasgow Focus Group |
|---|---|---|
| Solar | 7 | 10 |
| Wind | 8 | 9 |
| Tidal | 5 | 6 |
| Hydro | 8 | 9 |
| Biomass | 3 | 5 |
| Methane/Landfill | 1 | 4 |
| Geothermal | 2 | 1 |
| Wood | 1 | |
| Dung | 1 | |

Some of the New Lanark group members were well- informed regarding renewable energy technologies. Most members knew about solar, wind and hydro technologies followed by tidal and biomass.

**2.3.2. Question 'Following this evening's discussions have you learned about other renewable energy alternatives? If yes, please list below:'**

| Energy Technology | Lanark Focus Group | Glasgow Focus Group |
|---|---|---|
| Solar | 1 | |
| Tidal | 2 | 5 |
| Hydro | | 1 |
| Biomass | 3 | 6 |
| Methane/landfill gas | 4 | 3 |
| Photo-voltaic | 3 | |
| Geothermal | 2 | |
| Dung | | 1 |
| Fermentation | | 4 |

When asked this question, both the Glasgow and Lanark groups seemed to have (prior to the evening's discussions), known least about methane/landfill gas/biomass. Three of the New Lanark members also listed photovoltaic (but only one mentioned solar). Five of the Glasgow group claimed not to have known about tidal and four mentioned fermentation.

**2.3.3. Question 'Before tonight's discussions, which renewable energy technologies would you have chosen as being 'best' for the environment and your community? (please name two):'**

| Energy Technology | Lanark Focus Group | Glasgow Focus Group |
|---|---|---|
| Solar | 2 | 10 |
| Wind | 6 | 1 |
| Tidal | | 2 |
| Hydro | 8 | 8 |
| Biomass | | 1 |
| Fermentation | | 1 |

The response to this question highlighted some interesting differences between the groups. Hydro power was the most popular choice at New Lanark and second most popular with the Glasgow respondents. Most popular with Glasgow members was solar. Only two respondents in Lanark chose this option, preferring instead wind power.

### 2.3.4. Question 'Following tonight's discussions have you changed your mind? If yes, which renewable energy sources would you now choose and why?'

All 8 respondents from the New Lanark group said they would not change their minds but 4 said they would now add Biomass/landfill gas to their list.

In Glasgow, 10 of the 12 respondents said they would not change their minds, 2 would now consider biomass. One respondent also stated they would consider waves following the evening's discussions.

| Energy Technology | Lanark Focus Group | Glasgow Focus Group |
|---|---|---|
| Abundant | 3 | 6 |
| Sustainable | 2 | 3 |
| Cleanliness | 4 | 2 |
| Low environmental impact/ Environmentally friendly | 3 | 7 |
| More localised production | 1 | |
| Frees society from the grip of multi-nationals | 1 | |
| Natural | 1 | 5 |
| Cheap/Cost efficient | 3 | 5 |
| Aesthetically pleasing | 1 | 6 |
| Easy to install | 1 | |
| Provides employment | 2 | |
| Creates individual and local responsibility | 2 | |
| Small scale possible | | 1 |
| Low maintenance | | 2 |
| Efficient | | 5 |
| No By-products | | 2 |
| Hidden | | 2 |
| Doesn't affect wildlife | | 3 |
| Easily transported/storable | | 2 |

There was a tremendous spread of characteristics which members stated were important to them. The most popular for the New Lanark group were cleanliness, followed in equal measures by abundance, low environmental impact and cost efficiency. The Glasgow focus group members favoured first low environmental impact followed by abundance and aesthetically pleasing. Also popular was naturalness, cost efficiency and efficiency. Interestingly although employment was mentioned more by the Glasgow sub-groups, it was not chosen by any individuals as important.

**2.3.5.**

**Question' Given a budget of 100 counters, which renewable energy sources would you invest in personally? '**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Solar | 10 | | | | | | | |
| Wind | 30 | 20 | 9 | 19 | 20 | 30 | 10 | 50 |
| Tidal | | 20 | 12 | 20 | 10 | 15 | 20 | |
| Hydro | 30 | 20 | 38 | 21 | 60 | | 70 | 50 |
| Biomass | 15 | 20 | 40 | 39 | | 30 | | |
| Methane/landfill gas | 15 | | | | 10 | | | |
| Wood | | | | | | 25 | | |
| Dung | | 20 | | | | | | |

| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Solar | 40 | | 20 | 20 | 100 | 20 | 75 | 25 | 20 | 20 | 40 | 25 |
| Wind | | | | | | | | | | | | 50 |
| Tidal | 20 | | 20 | 30 | | | | | | | 20 | |
| Hydro | 40 | 30 | 60 | 50 | | 60 | 12.5 | 50 | | 40 | 40 | 25 |
| Biomass | | 70 | | | | | | 25 | | 40 | | |
| Methane/landfill | | | | | | 20 | 12.5 | | | | | |
| Fermentation | | | | | | | | | 80 | | | |

| | % selected by New Lanark | % selected by Glasgow |
|---|---|---|
| Solar | 2 | 34 |
| Wind | 26 | 4 |
| Tidal | 14 | 8 |
| Hydro | 41 | 34 |
| Biomass | 20 | 11 |
| Methane/Landfill | 4 | 3 |
| Wood | 3 | 2 |
| Dung | 3 | |
| Fermentation | | 7 |
| | | |
| | | |

The top three technologies selected by both group were:

| | New Lanark | Glasgow |
|---|---|---|
| 1st | Hydro | Hydro |
| 2nd | Wind | Solar (first equal) |
| 3rd | Biomass | Biomass |

Perhaps not surprisingly, the individual results varied from the subgroup exercise. Hydro power came out top with both groups but Glasgow members favoured this equally with solar energy. Interestingly, the New Lanark individual seemed to favour wind power (followed by biomass) much more than solar energy.

APPENDIX I

## Renewable Energy – May 26th & 27th, 2003
## University of Glasgow

*Objective: To find out what characteristics or attributes of renewable energy technologies make them more or less desirable to members of the general public.*

Potential Issues:

- Public may not know about the full range of technologies therefore may need some education. Care must be taken to avoid 'leading'.
- There may be some confusion over what an attribute is – e.g. they may not even consider employment as an attribute.
- There may be a conception that alternative energy sources are too expensive and cost may present a barrier. It is therefore important to stress that there is money for alternative energy sources from Scottish Executive.

The following script is to ensure that both Focus groups are approached in as uniform a manner as possible.

**"The University of Glasgow is conducting a preliminary study to determine what characteristics of green energy production are most favourable or least favourable to the people of Scotland. This information will be useful to planning boards and local councils in their decision-making process when developers of renewable power projects make applications to build in Scotland. This focus group is helping identify opinions about good or bad characteristics of the different renewable energy technologies.**

**Background**
**Electricity is one of the most important products consumed in modern society. With greater knowledge about our environment, a critical characteristic about electricity has become the source of its generation. We ask if it is polluting our land, water and air? Also is the source of generation depleting or damaging the resources of the region or planet?**

**There are many types of technologies that are classified as renewable. The two most important characteristics of these technologies are that fossil fuels or nuclear energy are not used and that the natural environment is not depleted or damaged by the conversion of its energy to electricity for us.**

**The Scottish Executive has committed Scotland to significantly increasing its renewable power production by the year 2010. England and Wales have also made major commitments to increasing their use of green renewable power.**

**This goal has been established in an effort to reduce the use of power plants that use fossil fuels (coal and natural gas) to generate electricity. Fossil fuel power plants are a major contributor to global climate change gases, commonly known as greenhouse gases or global warming gases.**

**Regardless of the type of renewable technology used, the price of electricity sold to businesses and consumers will not be different. Also, taxes will not be changed to promote or develop any of these technologies."**

## Part One

*The first part of the evening should be spent establishing pre-existing knowledge of the group. Care should be taken not to lead the discussion or introduce technologies that the group do not name themselves .The reason for the project should be briefly (see script). This part of the evening is designed to make the participants feel relaxed.*

Questions

1. Name the renewable energy sources you have heard about (Write answers on flip chart)

*Questions2 & 3 you should cover each named renewable source separately.*

2. If I were to ask you what characteristics of these technologies were good what would you say? (It may be useful to give an example such as saying that in the traditional world of energy industries such as coal mining a good attribute was that it was a major employer). (Write answers on flip chart).

3. What attributes of these technologies are bad? (Write answers on a flipchart). Again it may be useful to give an example using say coal – bad attributes would be unsightliness of bings, danger, pollution, etc.

4. As we mentioned earlier (script) the Scottish Executive are going to invest a sum of money in alternative renewable energy sources. This will incur a small cost on the price of electricity and taxes but the cost to the consumer will be the same regardless of what technology is chosen. I would like to get a feel for which technology you favour most of all from list 1. Can I have a show of hands for (then go down list one by one).

5. If I was to change the question slightly and ask you which of the technologies you would choose if the installation was on your own doorstep. Can I have a show of hands for (again go down list)

## Part Two

This part of the evening can be used to describe the technologies, which University of Glasgow want to discuss (power generating from – landfill gases, solid waste to recycling, sugar mill co-generation, wave power, solar panels, wind mills (sea and land), wood burning). Even if all technologies have been covered it would still be useful to summarise the information as there may be someone in the group less aware than others.

The group should be split in two. The following task should then be described.

***'Your group has been asked by the Scottish Executive to invest money in alternative energy projects. Your group has been given a budget of 100 counters to invest it in any number of areas it wishes. Within your group we would like you to come to a consensus and allocate this budget where you think it will be best spent. You will be given 10 minutes to come to an agreement. Once you have completed the task we would like the group to elect a spokesperson to explain why they made these allocations.'***

The groups will be given a card to help this process:

| Energy Source | Budget | Reasons |
|---|---|---|
| X | | |
| Y | | |
| Z | | |
| Q | | |
| A | | |

## Part 3

Thank you very much for your help this evening; your input has been very greatly appreciated. Before we hand you your envelopes could you please take the time to fill in this very short questionnaire. We need certain information for our records and it would also be very valuable if you could let us have your individual thoughts on tonight's discussion. Thank you.

**APPENDIX II**

**Transcription**
**Glasgow University 26th May, 2003**
**Focus Group 1 (New Lanark) – Renewable Energy**

MD – What types of renewable energy do you know about?
Group – Waterpower, wind, solar, geothermal (heat from the earth), tidal, wood, macadamia nut shells!
MD – well that's a waste
Ari – Put down nuts
Group – dung, all types of dung, organic waste
Group – animals?
MD – like on a big wheel!
Group – that can be classified as wind and dung!
Group member A – you can only really put down two – that's the waterpower and the wind power in this area.
Group – what about the sun!
Group – there's a lot of gas produced by that septic tank at the bottom of the village!
Group member A – well I don't know ... for all we see of the sun!
Group member B – you don't need the sun though you just need light, you just need daylight.
Ari – who mentioned solar? What were you envisaging when you said that?
Group – panels on the roof
Ari – Okay – like hot water solar?
Group – I don't know what they do but they are panels on the roof, and they catch rays or whatever... whatever the sun does it's converted.
Group – Because it's not the heat from the sun that ... you don't need sunshine...
Ari – well, we'll get into it.
Group – have we missed any? Any more to add to the list?

Summary of Renewable Energy Sources Named by the Group

- Water
- Wind
- Solar
- Geothermal
- Tidal
- Wood
- Nuts/burning waste
- Dung/organic waste
- animals

MD – We'll have to wait. It's only because we want to find out what's in your headfirst. I want to draw out the characteristics of each one before we elaborate.

MD – Characteristics. Take it away from renewable energy. Say we look at coal – a good characteristic might be it gives a lot of heat or a lot of employment and a bad effect could be as we mentioned already the effect on global warming. So the ones (renewable energy sources) that you've brought up, I just want to go through them and pull out good and bad characteristics that you can think of. We'll go down the list you've given me.

Group – plenty of, plenty of water.
Ari – yes, it's very renewable
Group – clean
Ari – what do you mean by clean? Water's clean?
Group – the fact that it's renewable, it's not, there isn't waste from it. So you're not producing say sludge from it or muck, fumes...
MD – Thanks, we just have to check that we don't put in our own opinions.
Group – cheap. The bad side to water would be if you were building a dam and you would probably damage the environment or make it unnatural (like at Pitlochry). Or you would have to fill land, which didn't have water to force it into another place to get the energy.
Group – You've got plenty of catchment areas in Scotland really when it comes to that aspect of it. Water is always there. Well it is as long as we keep getting the rain. Water as against wood fires, where are you going to get the wood continually to keep the fires burning to get energy? You're going to run out of forests in no time. Ten years and your going to be scratching your head looking for forests, whereas with water it's always there.
Group – Well it is as long as you keep getting rain. I don't think we'll ever run out but we do have droughts. At the moment the gases are changing the climate just now so what's to say that we won't be affected and eventually run out. It does have that possibility.
Group – climate is a big factor. And affecting water tables.
MD – Anything else – good or bad?
Group – we've only spoke about water in large dams but there's lots of areas where we could use it more locally. For instance in modern houses you can get conductors on the roof, have got little wheels and can generate enough electricity to give you some lighting or heat your water in the house.
MD – If I say it can be used on different scales would that describe that?

| GOOD | BAD |
|---|---|
| Plentiful | Dams (unnatural, damage the environment) |
| Renewable | Large areas may be flooded |
| Clean | Reliant on climate |
| Cheap | Disturbs water tables |
| Used on different scales - flexible | Noisy |
| | Visible |

MD – Okay I won't milk it. The next type is wind.
Group – What you've got is the hills here for these wind farms. They say they're unsightly but I don't think they're unsightly. Okay stick 1000 up it's gonna be unsightly.
Group 2 – But it's the noise they make. The noise if you're beside them.
Group 3 – But it would be unsightly if you had that put in your view. For instance if you lived in a cottage in the highlands and all of a sudden you got 10 wind farms put in front of you, and it's obscuring what you used to see as a vision. So really it's unsightly in that respect.
Group 4 – But what's more important, the air you breathe or your environment? There's got to be sights.

Group – But if you're going to get cheap electricity out of it, it's one of these things you could grin and bear if you were going to get cheaper electricity.
Group – I think noise is true of water too – if you've got big pipes...
Group – I must admit when I was going through the Lake District and turned the corner and the 3 big windmills just hit you .. you know the bit of the road? I think it's the most amazing sight.
MD – You think it's good?
Group – so architecturally, it's the aesthetic qualities.
Group – Well if you think of all those pylons that cross the country. I don't think you can say wind farms are any worse.
Group – why do they paint them white? It would blend in.
Group – the great thing about Scotland is you can place them anywhere. I think any industrial estate of more than 10km I think they should put in a wind turbine.
Group 2 – it doesn't have to be on a hill, they can put them in valleys – you can get the wind coming through the valley.
Group 3 – they still need to be properly placed to pick up that. I don't know how easily these are to produce?
Ari – well you've got to put them where the wind is!
Group – so you've got to consider that. That's the down side – not enough... wind dependent.
Group 2 But it's also, if you're looking at characteristics, it's clean. We can maybe argue that it's plentiful..
Group 3 – you are already getting the picture that you can't just work with one because of the dependency on the rain and wind and so you would have to have a blend.
Group 4 – well that's a thing that's going to have to happen in the future because you've got coal, what else .. Nuclear power. You've got them two working together which your going to have to phase out... so they're going to have to get an alternative just to take their place in the next century. The next 20 –30 years.
Group 5 –can be small as well. I think I've seen something about the size of a satellite dish that you can put on your house – a micro-turbine.
Ari – scalability (in good column)
Group 6 – it's probably more portable than water. Water has to be located in a place whereas wind is everywhere. You can't have water next to your house but you can have wind. Flexibility.

Summary of Wind Power

| GOOD | BAD |
|---|---|
| Aesthetically pleasing | Ugly |
| Clean | Noisy |
| Reliable | Expensive infrastructure |
| Plentiful | |
| Flexible size | |

MD – We'll try and move on. Solar.
Group – expensive,
Group 2 – do you mean the infrastructure is expensive?
Group 1 – well it's the old thing, how do you convince everyone to put panels on a house that's already built? Do you lobby people to get builders to put panels on every new house that's built?

Group 2 – it's because the panels are expensive. The actual electricity generated isn't expensive. It's the infrastructure.
Groups 1 – it's putting the equipment in and the maintenance of that equipment. You know how do you convince people that solar panels are easier to maintain? Certainly in Hamilton there was a large council scheme where they tried and the council didn't bother repairing them.
Group 2 – perhaps that's because the emphasis was on a test rather than the norm?
Group 1 – even so, I am unaware of whether you can have a massive solar farm? Solar farms would take up a lot of space to generate the power that we need so unless you're putting into individual buildings, properties – it's going to be expensive to start up.
MD – That's your perception that it needs a big area?
Group – the first place for this is going to be industry it's not going to be domestic anyway?
Group – well you can because you can have photovoltaic cells, photovoltaic tiles on your roof. You don't have to have a huge big solar panel. You can have roof tiles that are solar capturing.
Group 2 – imagine yourself in a house with a sixty grand mortgage. Your not going to put them in to save a small bit on electricity your going to need legislation.
MD – If I put this as household solar energy.
Group – but you still have to pay either on its installation or consumption.
Group 2 – I agree with you but very few people on modern estates, are going to have a wind turbine on their estate – they're going to depend on large wind farms that send power into them.
MD – I'll come back to the statement that all the forms will be the same price to the consumer. But I take your point about it if it is a household.
Group – a utility company isn't going to come in and wire us all for sound.
Group – solar is flexible as well.
Group 2 - I suppose a bad point is that people don't think it's possible here.
Group 3 – It's the limited supply – which local panels can provide you with. Every program I've ever seen is about new modern house, the panel s are there and it's going to provide you with enough electricity to maybe heat some water or give you night lights. It's not going to give you power – you're still dependent on something else.
Group 4 – in Scotland I think there would be a bit of a hiccup on that aspect.
Group 5 – Annie was saying that you don't actually need sun it's the light. Is that right?
Group 6 – the sun's rays are always there.
MD – It doesn't have to be blazing sun.
Group 5 – so that's a bit of a red herring.
MD – It's the perception that we are interested in.
Group – I was under the same impression as you – you needed sunlight.
MD – I think Ari will talk a bit more about that.
Group – well I think the panels on your roof are good it fits easy, it's cheap and it's instantly effective.
Group 2 – but if you go round building control will tell you you've got to have a certain colour of tile on your roof.
MD – As an individual I suppose you are doing something of your own choice.

Ari – Building codes?
Group – Building regulations.
Ari – Okay, I'm going to cross the line because it could be both bad and good.
Group – If you get legislation say from the Scottish Executive that you must have it then you're using regs in a good way, but at the moment ...
Group – How would the costing structure be like with solar? At the moment if you have wind or water which the company would be producing, the solar you're producing yourself.
Ari – to actually answer your question, in places, in other countries, in certain places in the States, power companies come in and give you $50 / year to put them on your roof. They collect the power, which happens to go straight into your house and then you pay them your regular utility bill. That way you lay out nothing but it really belongs to them and they are renting space.
Group – so is it going to cost you to have solar?
Ari – the way they're doing it in Scotland – no.
Group – so that would be cheaper?
Ari – ultimately though, regardless of which technology, which types of energy used, the price you pay for electricity, whether it's a solar or wind, it will cost exactly the same. Because it's green, it will cost the same. A really innovative way of managing this, regardless which type of renewable energy is used, the price you pay for electricity will be the same.
Group – so is this a way of saying that if you stop all conventional nuclear forms of electricity and they'll stop charging fossil tax?
Ari – actually, they have done away with the fossil fuel tax. Actually, they've suspended it just now. Remember, we are just talking about renewable.
Group – there's a change over problem.
MD – that won't be dealt with
Ari – we're just talking about the renewable branch.
Group – well I'm a consumer and for my electricity and gas I have a little meter in my house but now you're going to say that all my roof, the panels belong to a utility company and maybe come up and service it?
Ari – I'm not saying that that's going to be the case here. I'm just saying there's ways around you paying for the panels yourself.
MD – I think it's valid to raise that as a concern. Lack of control/ privacy?
Group – who actually owns it?
Ari – who owns it. Depending on how you look at it that can be a good or bad.
Group – it's funny you tend to look at renewable like that – you look at ways you can make it yourself. You don't think of that with fossil fuel – you don't think I'll have a generator, build my own. But now that all the renewable forms are coming up you think 'I could just do that myself'.
Ari – so that's a characteristic. How personal is it?
Group – would it not be cheaper to produce than the other two?
MD – well I don't know but that's you're perception so I'll put that down as good. It doesn't need to be true but it's a valid perception.
Group – cheaper for the person who's going to consider the three.

Summary of Solar Energy

| GOOD | BAD |
|---|---|
| Clean | Expensive for households to install and maintain |

| | |
|---|---|
| Flexible | Need a big area |
| Easily installed | What happens in winter? |
| Good for households | Intermittent |
| Personalised | Need building regs / impact on the value of your property |
| Cheap | Don't know who owns it |
| | |

MD – Any more? Okay the next one is geothermal.
Group – well I think David Ike said the next eruption will be on the Isle of Arran so we should go and buy land over there if there's going to be a volcanic eruption!
MD – okay Annie?
Group – well a bad thing is not many people know about it.
MD – who would have known about geothermal or would have considered that? Four out of 8.
Group – using the heat from underground to make power, heat, and electricity. You can use the heat from old mine shafts, if you happen to have them, and as you know, Scotland is riddled with mineshafts. Or you can just dig a trench a few feet deep. The further down you go the higher the temperature ... 10 degrees for every 100m or whatever it is you go down. But it's certainly not enough to heat .. to give you a whole heating system but it can provide enough heat-to-heat water to a certain temperature that can help reduce your reliance on fossil fuels. They use it a lot in other countries. There's two geothermal schemes – one in Shettleson in Glasgow and it heats about 40 houses and another one in Perth, but they're both quite small but very successful. The whole point of them is it's combined with a community energy system such as I have to say we have in New Lanark where we have a single boiler feeding all of the houses.
Group 2 – well I've worked at 1000 feet underground and I cannae say it was that hot to generate heat.
Group 1 – yes but it's surprising how much there is?
Group 2 – no the further you go to the earths core, the more heat you're going to get.
Group 3 – I'm sure that must be more costly?
Group 4 – the assumption that whatever Maggie is saying is that the price to us will be the same.
Ari – how it's being structured is that your electricity bill whether it's for heating water or T.V., regardless of whether it's geothermal or wind, will be the same.
Group – again I think you'd have to be talking about big areas. Again, I'm not that up on geothermal but I'd have thought you needed... you know ... your saying one of the ways is to have trenches... surely that means you've got to have lots of trenches and how do you cover up that trench?
Group 2 – it's just like a tube, a pipe and the heat of the earth warms the water.
Group 1 – but your still going to use a large piece of land. It's like building a house – you have to put the utilities in but at the end of the day you're probably using up the same space but a the end of the day to produce the volumes you'd need I'd have thought you'd need more space.
Group 2 – it's another way of producing renewable energy, it's not a solution on it's own.

MD – I don't think there's going to be one solution, I think it'll be a combination approach.
Ari – no, not in our lifetime. That's my opinion. They'll be no one solution. It'll be a combination. And believe me the needs in say Canada are different from Scotland versus Mexico. Actually in all of Scotland it's pretty uniform, unless you're in the Highlands.
Group – would that disturb the balance (in the earth) if you done it on a large scale.
Group – if you take too much heat off?
Group 2 – I mean we're not going to produce our own Mount Vesuvius or anything like that? I mean the ones in Glasgow is it actually fires in the mines?
Group 3 – no the one in Shettleson is ... I don't know if they used a mineshaft or trenches. I'm not sure
Group 4 – the mineshaft makes you think of the bings, spontaneous combustion.
Group 3 – It's nothing to do with fires it's just the heat.
MD – how would you summarise this?
Group – I suppose you could say one of the bad things is that it will never be enough on it's own. It's got to be combined.
Group 2 – it's less accessible.
Group 3 – at the moment in this country but it's used widely in others. We're way, way behind. Sweden and Scandinavia are way, way ahead of us in terms of community heating systems.
Ari – then you can go to Iceland where they generate mostly al of their electricity and heat for free.
Group – that's another thing. Like the other renewable energy systems, essentially the source is free. It's the infrastructure to catch the energy that's expensive.
Ari – yeah the energy source is free almost by definition.
Group – it's the commitment of the country itself to develop these systems that's important.
Group 2 – people here aren't really interested. They just take their gas and electricity for granted. They don't know anything about geothermal or solar or anything.
MD – Scott you're our youngest member. In terms or renewable energy have you ever heard of geothermal?
Scott – no never.
MD – have you heard much about the others?
Scott – oh yes, solar power we did a lot of at school.
MD – Good or bad?
Scott – don't know, never really thought about it!
Group – a good thing about that is we don't have windmills and people saying that's unsightly.
Ari – not visible
Group – but then by the same thing it probably takes more effort to put it in.
MD – I suppose given our ground conditions, it might do in Scotland. Put down difficult to install?
Group – and distributions probably going to be a bit more?
Group 2 – different areas have different types of power. We're talking about say take that to Glasgow, that would be costly because the nearest place to draw heat

from the ground would be peat fields. But to move that into Glasgow, I don't think that would be feasible. Different areas, different types of heat.
Group – is this looking at transportable energy?
Ari – we are looking at things that ... transportable in that it will either replace electricity or be turned into electricity.

Group – so you don't have to put a pipe on every street or a windmill on every house? You can transport it?
Ari – it's like the system your talking about replaces electricity you use to make hot water or it replaces the methane gas boiler.
Group – but it still going to be electricity.
Ari – but wind farms, you transport it 100 miles from where the farm is.
Group – so we don't have to think of it being round the corner?
Ari – this is why this is an issue. As the years go by, almost every community will have to develop some renewable energy within it's own space.
Group – could geothermal be fed into the National grid?
Ari – no there's no place in Scotland that has hot enough geothermal. Iceland has that but it comes out as blast furnace hot. But this one would replace electricity or methane like in your boiler.
Group – is there an energy that comes off rocks? If you put ultraviolet light on rock. If you go to the rock museum there is ... they light up in all different colours?
Group 2 – but you're using power to make power.
Group 1 – I know but what I'm saying is ... is that anything you could use.
Ari –I don't know anything about it so I'd have to say, probably not.

Summary of Geothermal Power

| GOOD | BAD |
|---|---|
| Uses heat from the ground | Relatively unknown |
| Good to combine with other systems | Costly |
| Good for small communities | Large amounts of land needed |
| Source is free | Negative effect on the earth |
| Not visible | Difficult to install |

MD – Lets move on . Next is waste. The waste that was mentioned was dung.
Group – general compost.
Group 2 –general dung
Group 1 – when you say dung do you mean the heat coming off when it decomposes or the gas coming off the dung?
Group 3 – I was talking about in India where they collect all the dung and use it in fires.
Ari – okay, you have two types going on. One is where you burn it, whether it's for fire or burn it to create steam for a turbine and one is as it decomposes, catching the methane.
Group – but is that bad for the environment. The effect from the gases from that are bad. Smoke fumes bad too.
Group – tell me is methane released into the air damaging the ozone or is it worse if it's burned?
Ari – this is a question – 'is it good or bad that we're burning the gas'. I'll get into that

Group – it's difficult to collect.
MD – you just need big dung trucks!
Group – again you would need plenty of it. It's plentiful.
Group – not in my back yard! Yes it's plentiful as a household waste.
Group – if you're burning wood or nutshells, it's not releasing any more carbon dioxide..
MD – We'll put nuts with wood.
Group – it's smelly
Group – it's balanced
MD – sorry to skelp on. Anything else?
Group – has a by-product
MD – Is that good or bad?
Group – well it might be good. May be able to spread it on the land afterwards.
MD – Anything else?
Group – it reduces landfill.
Group – reduces collection.
Group – there would also be more human interaction. We would all have to do something.
Group 2 – you would need education. You would have to put the products in to what's good for waste and what's not good for waste. So we'd have to take more responsibility.
Group – it might be good or it might be bad because some people may not take on that responsibility.
Group 2 – you would need legislation. Animal and human waste will always be there but consumer waste has to be reduced. Very soon they're going to reduce the number of landfills dramatically in the next couple of years.

Summary of Waste as Renewable Energy

| GOOD | BAD |
|---|---|
| Gets rid of 'bad' gas | Burning causes pollution |
| Gas Flaring – better than putting waste into rivers | Needs collecting |
| Plentiful | Smelly |
| Reduces landfill | May produce harmful by=products |
| May encourage responsibility for recycling | Requires public to be educated |
| Reduces collections | |
| Could produce a good by-product | |

MD – Woods and nuts next
Group – bad smoke. We older folk remember when you couldn't see your hand in front of your face when you were burning fossil fuels. Smoke, smog, ill health.
Group 2 – they're actually using waste, chipped waste wood in commercial energy production.
Ari – less waste? Useful waste?
Group – recycling waste.
Group – not encouraging farmers to grow strips of willow to burn?
Group – has to be replanted. Regeneration.
Group 2 – the trees that you plant are going to soak up a lot if the smoke.
Group 3 – they produce more oxygen

Ari – cleaner air?
Group – it takes time
Group 2 – I just remember when they brought in smokeless fuel and thank god! In Hamilton and round about Motherwell where you had the steel works the smogs were a nightmare and the flues you got in winter through smog were dreadful.
Group 3 – you'd need plenty of it.
Ari – is that good or bad? Who's going to grow it?
Group – well exactly, again it's area. You need large areas so who grows it?
Group – it helps farmers diversify.
Ari – is that good or bad?
Group – it's good.
Ari – so it's good and creates unemployment
Group – someone mentioned willow because it grows very fast, okay so if you have to grow a particular species of tree will it change the eco-system. Also would it affect the water table?
Group – it would be a drain on the soil if you keep planting
Group 2 – again, people don't know about it. There's not enough knowledge about all of these. It's education, education, education.
Ari - just last week the Scottish Executive allocated 2.25.million pounds for a several year education programme on renewable energy.
Group – but was there not a wood plant built but was closed down just for the want of 3 million pounds?
Group – it might reduce our edible food. If farmers get money to plant wood, trees then the agriculture will not be balanced so there may be less food.
Group – so food costs may go up because we have to import food from abroad.
Group – also health because there would be more treatment to the food, which means it wouldn't be fresh anymore, which means we'd get sick.
Group – I don't know if we would allow it to become an issue whereby we wouldn't be producing food
Group 2 – we don't even eat our own lamb.

Summary of Wood as Renewable Energy

| GOOD | BAD |
|---|---|
| Recycles waste | Burning causes pollution |
| Cleans up air | Trees new time to grow |
| Helps farmers diversify | Requires large areas of land |
| Trees | Changes the ecosystem |
| Look good | Takes nutrients from the earth/ affects the water table |
| | Education required |
| | May increase the cost of food and detrimentally affect the quality of food (if imports increase) |

MD – I'm going to stop you there and end on tidal.
Group – wave power. It's paddles underneath.
Group – free, plentiful, totally sustainable

Group – the bad side of that is probably the transportation from the very edges of a country. So distribution is probably going to be an issue there.
Ari – again that's a cost issue for Scottish Power to worry about
Group – it suits Britain because we are an island
Group – out of our visibility.. mostly
Group 2 – would it affect shipping?
Ari – sure and fishing... use of the ocean
Group – swimming!
Group 2 – not good for animals as it disturbs their habitats
MD – Animals like:
Group – nesting birds, the algae round the coast that the shellfish depend on
Ari – wildlife and environment
Group – I don't think it would have that big an effect on wildlife.
Group 2 – if you were a seal and you went past a big mechanical paddle that took you head off you'd maybe think differently!
Group 2 – I thought these things just went up and down.
Group 1 – but it's an amazing amount of power you're talking about there. I don't know what speed they go up and down at.
Group 2 – what's going to happen if you have a big diesel-spewing machine on your coastline?
Group 3 – it's not going to be spewing diesel!
Group 1 – I don't know, how are you going to lubricate the machines?
Group 2 – water will lubricate nylon.

Summary of Tidal as a Renewable Energy Source

| GOOD | BAD |
|---|---|
| Cheap | Distribution may be a problem |
| Sustainable | May have an environmental impact |
| Good because we are an island | Effects wildlife |
| Clean | Affects shipping |
| Not visible | |

MD – Since we're on to specifics, we might as well get Ari to fill in the gaps and talk in more depth about some of the issues you've raised.
MD – Could I have a simple show of hands – if you had to choose one of these (as an individual) which one would it be?
Five voted for HYDRO and three for WIND.
MD – If I were to change the question slightly, and say that it would be on your doorstep, would you change your vote? – One person did and changed from WIND to HYDRO.

**Presentation by Ari (not transcribed)**

**Groups split into three groups of 2.**

**MA – I want you to imagine if you had a budget of £100 – what energy types would you invest your money in? What characteristics do you like about these technologies.**

| Group 1 New Lanark | | |
|---|---|---|
| Run of river | 20 | Water abundant in Scotland, Lots of room for several power stations, more aesthetic than other systems |
| Reservoirs | 20 | As above |
| Wave | 10 | As above |
| Wind | 20 | Lots of hills and valleys that will provide good areas for wind farms |
| Biomass | 10 | Prevents methane hitting the atmosphere and reduces global warming |
| Wood | 10 | Gives employment |

| Group 2 New Lanark | | Plentiful & clean |
|---|---|---|
| Hydro (run of river) | 21 | Abundant |
| Tidal | 20 | Saves pollution, by-product useful, provides employment, reduces waste |
| Biomass | 39 | Plentiful & clean |
| On shore wind power | 19 | |
| Solar panels | 1 | |

**Transcription**
**Glasgow University 27th May, 2003**
**Focus Group 2 (Glasgow) – Renewable Energy**

MD – What types of renewable energy do you know about?
Group – wind, waves, solar, hydro
MD – What do you mean by hydro?
Group – in dams using gravity, rivers
MD – Any more?
Group – recyclable waste
MD – What do you mean by that?
Group – domestic and municipal waste. Household trash.
MD – Anything else?
Group – animal waste, dung
Ari – what were you envisaging when you said 'solar'?
Group – well you hear so much about solar power that can create energy.
Ari – okay so you are talking about 'photovoltaic that go straight from sunlight to electricity?
Group – yes
Group – what about the other solar energy that heats water and comes through panels? You could use that to heat houses.
Ari – so you've got solar for photovoltaic, which is straight for electricity and solar hot water heating.
MD – Any more?
Group – alcohol

MD – What I want you to think about is what characteristics of each type of energy are either good or bad. We'll do it in the order you've given me:

WIND POWER

| GOOD | BAD |
|---|---|
| Environmentally friendly | Noisy (depending on the size of the generator. Okay if they are out in the sea or the middle of nowhere.. say on hills) |
| Noise free | They vibrate |
| Low maintenance | Bad for birds and wildlife |
| Looks nice in pictures | Ugly – blot on the landscape |

***The group acknowledged there were crossovers – e.g. one person noted that there would be fluctuating energy production (which would be bad) but another group member noted that this was okay as when there was a lot of energy created (on a windy day), it would be cold and more energy would be used and vice-versa.***

Group – would the power produced from wind farms be stored?
Ari – I will make one statement – with wind farms you can't store energy.
Group – is that why there's so many together and not just one alone?

Ari – it's easier to maintain 60 of them at once than say 60 in 10 different spots. So it's easier running them like a factory than spreading them all over the place. If they were individually placed they would probably be more pleasing.

WAVE POWER

| GOOD | BAD |
|---|---|
| Endless supply of waves | Location – accessibility difficult<br>Affects sea life and birds |
| Cheap | Unemployment – there wouldn't be the same amount of people employed to produce and maintain or anything like that |
| Natural | It takes up the seaside and the beach (not that Scottish beaches are very good – their too cold!) |
| Environmentally friendly | Depending on size and nearby beauty spots it could be unsightly as well, like a big pontoon floating across a beauty spot |
| | Maintenance – it could be dangerous because it's out to sea. Very, very hard to maintain. The very fact they're not in general use to a big scale probably points to that. |

Group – What about when the sea's really rough or really calm? How is it affected by the natural ebb and flow?
Ari – It depends on the types of wave power you're talking about.
MA – We'll just say it varies because what I'm trying to do is get what's in your head
Just now and Ari will fill in any gaps.

SOLAR

| GOOD | BAD |
|---|---|
| Cheap to run | Difficult to rely on if it depends on the sun. |
| Natural | If it's reliant on just daylight hours you're going to produce less electricity in the winter when you need more. |
| Panels so each house can generate it's own electricity | Ugly – but you can hide it on roofs |
| Adaptable – it's portable and can be hidden anywhere | High maintenance – do they burn out? |
| Can store small amounts | Easily vandalised |
| | |

Group questioned about whether sun was needed to generate power.
Ari – it depends on the type. One is solar hot water and the other one is the photovoltaic.
Group – does it store up what can't be used? How does it work at night?

Ari – again it depends. With solar-hot water yeah you can store the hot water in a boiler or cistern. Electricity – again it can be stored in batteries but it depends on how much.. yeah you can store a small amount in batteries.

MA – When we talked about hydro before we noted there were two types – one using reservoirs the other a river.
Ari – there are two major types of hydro. One is the traditional (where I come from) where you have a dam and you control and store the water then release it when you need energy. Then there's what you call run of river where during the daily flow you siphon off a little bit and run it through a turbine and it goes right back into the river. So you don't store the water – you just use it as it flows each day. Scotland has both types already – big and small. So you just have to be clear which one you're envisaging

HYDRO POWER

| GOOD | BAD |
|---|---|
| Easy to store | Ugly – big buildings |
| Some of the dams are quiet a tourist attraction (e.g. Pitlochry) | Dangerous (deaths at Barrhead Dam). Should be made out of bounds |
| Dependable | Dams destroy existing landscape/wildlife |
| Dams – low maintenance | Depends on weather – affected by drought |
| Cheap | Initially they change the environment for miles around |
| Reliable | |
| Fishing – encourages leisure & sports | |

RECYCLABLE WASTE

| GOOD | BAD |
|---|---|
| Reduces the amount of landfills | Take up a lot of space |
| Makes use of waste | Smells |
| Encourages responsibility and changes attitudes to the environment | Pollutes – burning |
| Creates employment | Bad for ozone layer |
| | Needs separated – needs lots of types of bin |
| | |

At this stage recording stopped but the group responses to the next two renewable energy sources was noted.

ANIMAL DUNG

| GOOD | BAD |
|---|---|
| Cheap | Smelly |
| Plentiful supply | Expensive to run |
| Creates employment | |

FERMENTATION

| GOOD | BAD |
|---|---|
| Creates employment | Smells |
| Uses waste products | Needs a lot of space |
| | Open to abuse |
| | Expensive |

MA – If I were to ask you to vote for one type of renewable energy, which would you vote for?:

SOLAR – 5 votes
HYDRO – 6 votes
FERMENTATION – 1 vote

MA – If I was to say that whatever you chose would end up next to you would you change your mind?

*No one changed his or her mind.*

**Presentation by Ari (not transcribed)**

**Groups split into three groups of 4.**

**MA – I want you to imagine if you had a budget of £100 – what energy types would you invest your money in? What characteristics do you like about these technologies.**

| Group 1 Glasgow | Percentage | Characteristic |
|---|---|---|
| Solar power | 40 | Can be stored (solar-hot water), environmentally friendly, can be hidden |
| Hydro-electric | 40 | Plenty of rain, scenic, low maintenance, fish farms for eating |
| Tidal | 20 | Natural, unlimited supply, cheap |

| Group 2 Glasgow | Percentage | Characteristic |
|---|---|---|
| Solar | 75 | Cheap, natural, hidden from people, no effect on the environment, cost effective (both types of solar) |
| Hydro | 12.5 | Highly efficient, low maintenance, low impact on the environment. Both types of hydro |
| Recycling | 12.5 | Uses natural produce, more access (involvement) for people |

| Group 3 Glasgow | Percentage | Characteristic |
|---|---|---|
| Biomass | 50 | Re-cyclable, neutral effect on the environment |
| Hydro-electric | 40 | Uses what is available, environment recovers from construction, aesthetically pleasing, freely available |
| Photo- voltaic | 10 | Makes us aware of energy uses because you know it is not an infinite supply |

**APPENDIX III**

# University of Glasgow
# Renewable Energy Technologies

| |
|---|
| Name: |

| |
|---|
| Date of Birth: |

| |
|---|
| Home Address: |
| |
| |
| Telephone No: |

## Individual Responses

3. Before this evening, what sources of renewable energy did you know about (please list)?:

| |
|---|
| |
| |
| |

4. Following this evening's discussions have you learned about other renewable energy alternatives? If yes, please list below:

| |
|---|
| |
| |
| |
| |
| |
| |

5. Before tonight's discussions, which renewable energy technologies would you have chosen as being 'best' for the environment and your community? (please name two):

| |
|---|
| |
| |
| |
| |
| |

6. Following tonight's discussions have you changed your mind? If yes, which renewable energy sources would you now choose and why?

7. Given a budget of 100 counters, which renewable energy sources would you invest in personally? (please use the below table).

| Energy Source | Budget | Reasons |
|---|---|---|
| X | | |
| Y | | |
| Z | | |
| Q | | |
| A | | |

**Please hand completed responses to your presenter and collect payment.**

**I have received payment of £20:**

**Signature:**

**Date:**